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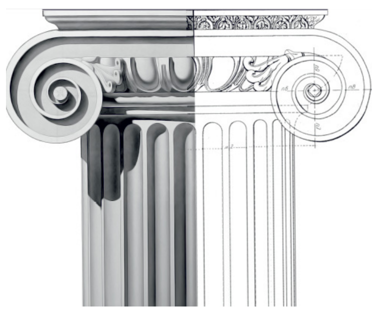

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THE 30TH OF OCTOBER SAMOS-GREECE EARTHQUAKE. ISSUES RELEVANT TO THE PROTECTION FROM STRUCTURAL DAMAGE CAUSED BY STRONG EARTHQUAKE GROUND MOTIONS

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Abstract

Introduction: This is a report of issues relevant to the protection from structural damage that is sustained by various types of structures when subjected to strong earthquake ground motions. **Purpose of the study:** This study became relevant due to the recent intense earthquake activity to the Greek island of Samos which left its impact on numerous structures of various types. **Results and discussion:** Initially, a summary is presented discussing the effort that has been made in Greece trying to confront with the consequences of this extreme loading condition to the built environment. Next, a summary report is given for certain types of structures which suffered the most. They include old Christian Greek Orthodox churches as well as other buildings on conservation status. The sustained damage is discussed together with a brief numerical study that tries to simulate numerically the observed behavior. Finally, a brief discussion with relevant conclusions are presented as a result of the observed damage combined with similar observations and studies made during the last decades.

Keywords

Earthquake structural damage, Christian churches, Cultural heritage, Samos island, Unreinforced masonry structures, Reinforced concrete structures, Numerical simulations.

Introduction

An earthquake occurred 16km North from the Greek island of Samos on the 30th of October 2020 (11:51GMT) with a magnitude of M6.7 (Figure 1). This island is located at the East side of the Aegean Sea an area seismically active (Ambraseys et.al., 1996; Ambraseys and Simpson, 1996; Papazachos, 1990). The main event caused widespread structural damage mainly at numerous low-rise old unreinforced masonry buildings of this island. It also caused heavy damage and collapse of multi-story reinforced concrete (R/C) buildings at the city of Izmir located at the coastline of mainland Turkey towards the North-East, approximately 60km from the epicenter of this earthquake. This study focuses on the effects of this seismic strong motion on the Greek island of Samos. The Institute of Engineering Seismology and Earthquake Engineering (ITSAK) operates a strong motion accelerograph at the city of Vathi, the capital of Samos. The ground accelerations at Vathi due to the main shock were recorded by this instrument (see preliminary report of ITSAK (Preliminary report, October 2020) and ETAM (Preliminary report, November 2020) having peak horizontal ground acceleration 227cm/sec^2 and peak vertical ground acceleration 134cm/sec^2. The main event was followed by a considerable number of aftershocks, with the aftershock sequence being active for sometime. (Figure 2).

Figure 1. Map indicating the epicenter of the 30th of October 2020 seismic event

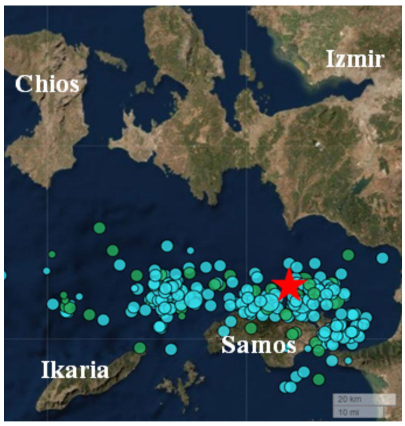

Figure 2. The epicenter of the 30th of October 2020 main event and the following aftershock sequence

Figure 3. Map of the North coast-line of the island of Samos where the two main cities of Vathi and Karlovasi are located

The most spectacular structural damage could be observed at the two main cities in the island, its capital (Vathi) and Karlovaisi 25km to the West (Figure 3). Due to the location of the epicenter, having the same epicentral distance from both Vathi and Karlovasi, and due to the generating mechanism of this earthquake that followed an almost East-West fault line, as can be seen from the aftershock sequence, it can be reasonably assumed that the strong motion characteristics at Karlovasi would be quite similar to those of the recorded strong motion at Vathi. This assumption will be made use of in the section presenting selected numerical analyses predictions of the structural response of damaged buildings.

A few minutes after the main shock the waterfront of Vathi was subjected to a tsunami which, despite its relatively small height, flooded the shops located at the waterfront causing considerable damage to its contents (Figure 4). Moreover, a permanent uplift of approximately 20cm was noticed at the embankment of the waterfront after the end of the current earthquake sequence (Figure 5). Apart, from the structural damage at the two main cities of Vathi and Karlovasi, widespread damage was also observed for unreinforced masonry structures located at many villages of this island. Despite the fact that this earthquake was also felt at the neighbouring Greek islands of Ikaria and Chios no structural damage was reported there.

Main issues towards protection from structural damage

During the last fifty years various parts of Greece have been subjected to a number of damaging earthquakes ranging from Ms=5.2 to Ms=7.2 on the Richter scale (Manos, 2011). Some of these earthquakes, not necessarily the most intense, occurred near urban areas and thus subjected various types of structures to significant earthquake forces leading to damage. Manos (Manos, 2011), lists information relevant to these events and discusses the observed structural damage as well as the effort that was made in Greece towards increasing the

Samos Earthquake 30-10-2020, Damage from the main event at the city of Vathi, capital of the island of Samos. The interior of the shops at the water front was damaged by a tsunami that followed a few minutes after the main shock

Figure 4. Indication of the tsunami at the waterfront of Vathi

Samos Earthquake 30-10-2020. There were signs of 20cm land rise at the water front.

Figure 5. Permanent uplift of the embankment at the waterfront of Vathi

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earthquake protection and reducing the seismic risk. The main conclusions are also listed here.

1. Classification of structural damage and their underlying causes: *Improve effective measures to contain damage* (Organization of Earthquake Planning and Protection of Greece (OASP), 2001).

2. Repair and strengthening of damaged structures*: Improve the means of such interventions by establishing relevant code provisions as well as by introducing effective methods and techniques* (Organization of Earthquake Planning and Protection of Greece (OASP), 2001).

3. Upgrade the seismic design: *Revise the Seismic Code provisions* (Paz, 1994; EAK-2000 Greek seismic Code; Provisions of Greek Seismic Code with revisions of seismic zonation, 2003; ELOT EN 1998-1/2005-05-12).

4. Plans for earthquake preparedness: *Assimilate past experience and provide for effective future plans and actions.*

5. Assessing the vulnerability of certain type of structures (schools, hospitals, public buildings etc.): *Introduce measures for upgrading their seismic resistance* (Organization of Earthquake Planning and Protection of Greece (OASP), 2001).

6. Education specialized in earthquake engineering: *Introduce specialized studies in Universities. Establish special courses for the retraining of Engineers.*

7. The enrichment of the strong motion data base: *Expand the national network. Introduce specialized networks with modern instruments in dams and bridges.*

8. *Address the problem of old structures built without seismic design provisions which include structures of cultural heritage to be preserved.*

A discussion of the above issues will be the main objective of the present studies using the recent experience from the structural damage observations caused already by the recent earthquake at Kefalonia island (Manos and Kozikopoulos, 2015) and the current Samos island earthquake sequence (Preliminary report, November 2020) as stimulus for this purpose. As a starting point of this discussion the following facts must be listed:

a. Referring to ***point 1 above,*** the classification of structural damage and its underlying causes for structures built in Greece with reinforced concrete (RC) is being well understood, utilizing the observations selected during the earthquake activity of the last 40 years. Manos (Manos, 2011), tried to summarize some of the most outstanding cases which are also listed here.

b. Referring to ***point 2 above***, design provisions has been published as a legal documents for assessing the vulnerability of existing RC structures as well as for designing the necessary interventions towards upgrading their resistance for future earthquakes (Organization of Earthquake Planning and Protection of Greece (OASP), 2001). Moreover, similar provisions have been currently published in draft form to be valid for existing masonry structures. Moreover, the Greek Organization of Earthquake Planning and Protection (OASP) has supported financially numerous research projects which focused on confronting with the earthquake vulnerability of existing structures. The same objective had the financial support of funds provided by the European Union. The actual effect of all this research will be discussed further.

c. Referring to ***point 3 above***, apart from issuing a New Greek Earthquake Resistant Design Code since 1995 (EAK-2000 Greek seismic Code; Provisions of Greek Seismic Code with revisions of seismic zonation, 2003) the relevant seismic design provisions of the Euro-Code (Euro-Code-8, ELOT EN 1998-1/2005-05-12) have become active and are applied as design provisions for all structures that are built in Greece since 1995. Apart, from particular design provisions included in these codes, which are in accordance with current knowledge in Earthquake Engineering and Earthquake Resistant Design, they also include provisions relevant to defining the design spectra as well as new seismic zoning. This represents a considerable upgrading in resisting the effects of strong earthquake ground motions. Figure 6 depicts the current new seismic zoning map of Greece together with the corresponding horizontal design ground acceleration levels. The island of Kefalonia belongs to Zone III whereas the island of Samos belongs to Zone II with horizontal design ground acceleration equal to 0.36g and 0.24g, respectively (g the acceleration of gravity).

d. Referring to ***point 4 above,*** the Greek Organization of Earthquake Planning and Protection (OASP, https://www.oasp.gr/en) has assimilated past damage experience and has being active in distributing relevant publications in schools

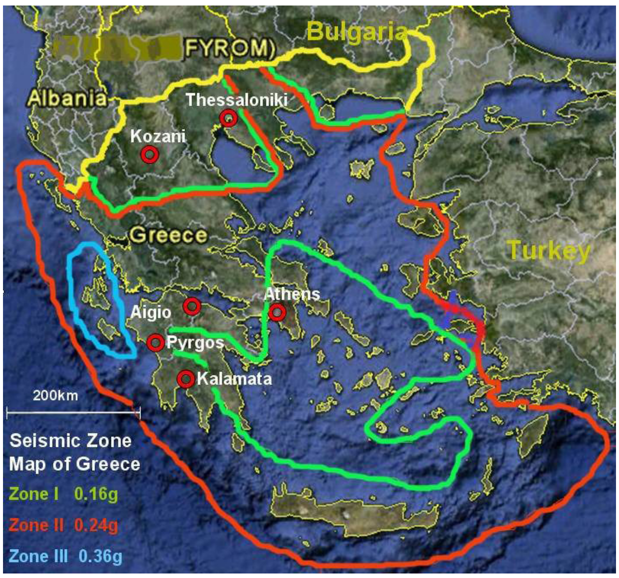

Figure 6. The seismic zoning map of Greece

and universities. Moreover, this organization has upgraded all the actions relevant to earthquake emergencies. This was shown to be effective both in the recent earthquake events of both Kefalonia and Samos islands.

e. Referring to ***point 5 above,*** an upgrading was established in the design and construction of structures for these particular structures (schools, hospitals, public buildings etc) which were built since 1995, when the provisions of the new seismic code of Greece were enforced, till today (EAK-2000 Greek seismic Code; Provisions of Greek Seismic Code with revisions of seismic zonation, 2003). However, the upgrading of existing structures that fulfill these functions and were built prior to 1995 is progressing with low pace (Organization of Earthquake Planning and Protection of Greece (OASP), 2001; Paz, 1994).

f. Referring to ***point 6 above***, a large effort has been accomplished in seminars for professional engineers on issues referring to the seismic behaviour of structures and on upgrading their seismic resistance. Moreover, a large number of postgraduate one-year courses are running for the last 20 years in all the departments of Civil Engineering of the major Greek universities focusing on all aspects of earthquake resistant design of new and existing structures.

g. Referring to ***point 7 above***, the existing National Network of strong motion accelerographs was enriched with numerous new instruments and covers the whole of Greece. During the last 20 years these recordings have been stored on a data base that is managed by the Institute of Earthquake Engineering and Engineering Seismology (ITSAK see (Preliminary report, November 2020)). The resent Samos earthquake ground motion was recorded by such instrument. Moreover, certain important structures, e.g. the large cable stayed bridge at Evripos-Halkis, have been also permanently instrumented.

h. The seismic vulnerability of old structures constructed before the enforcement of earthquake resistant design in Greece (1958) represents one of the most difficult problems (Manos, 2011). This is evident after a strong earthquake event in Greece with this type of structures being severely damaged in many localities. This is covered in many past publications. One category of structures with a heavy toll is old Christian Orthodox churches (Manos and Kozikopoulos, 2015; Manos, Soulis, Karamitsios, 2012; Manos and Karamitsios, 2013; Manos, 2016; Manos, Kotoulas and Kozikopoulos, 2019; Manos and Kotoulas, 2019). Another type of vulnerable buildings are those with particular architectural features which were declared to be under conservation; this means that the owners should abide with a particular legislative framework dictating the rules of any works to be done in such a structure (Manos and Papanaoum, 2009). This issue is partly discussed here taking advantage of the stimulus given by the recent “Samos” earthquake. The two main cities of the island of Samos, e.g. Vathi, the capital of the island, and Karlovasi, included such old buildings which sustained structural damage as will be shown in the following. Moreover, old churches were also heavily damaged. Similar damage was also widespread in the surrounding villages. In what follows, typical damage of this type will be presented and discussed. It must be underlined here that relatively modern structures built with a degree of seismic resistant design, despite the intensity of the ground motion, are reported as not developing any structural damage, with a few exceptions. On the contrary, in the nearby city of Izmir in Turkey a large number of RC multi-story residential buildings collapsed with a heavy death toll (Figure 7). Although the report for these collapsed buildings is pending it should be underlined that the Turkish seismic design code and the construction practices in Turkey have been upgraded well after the upgrading that was enforced in Greece in 1995 together with the Euro-Codes (ELOT EN 1998-1/2005-05-12; EN 1996-1-1:2005) sometime afterwards. It is believed, that the enforcement of the provisions of the “New Seismic Code of Greece” (EAK-2000 Greek seismic Code; Provisions of Greek Seismic Code with revisions of seismic zonation, 2003) together with the Euro-Codes has reduced substantially the seismic


Figure 7. One of the many collapsed multistory buildings at Izmir-Turkey

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vulnerability of the structures designed and built in Greece according to these provisions after 1995.

Earthquake performance of multi-story reinforced concrete buildings in Samos

As already mentioned, in contrast to the collapsed multi-story buildings at Izmir-Turkey (Figure 7), fortunately very few reinforced concrete buildings in Samos Island sustained structural damage. Figure 8 depicts such a case of damaged columns at the ground floor of a RC multi story building. This particular structural deficiency of a “relatively” flexible ground floor for RC multi-story buildings in Greece has been identified for some-time (see Manos, 2011) This is due to the fact that the shear force demands at this level are amplified because of the increased stiffness of the upper floors, which is not accounted for in design that ignores the influence of well-built masonry infill in these upper floors. Moreover, the old design provisions did not focus on shear reinforcing detailing of these ground floor columns to provide for sufficient shear strength to meet such shear amplified demands.

Unfortunately, this structural deficiency which leads to such high-risk structural damage for the safety of RC multi-story buildings is systematic and is present in numerous RC multi-story buildings designed and constructed in Greece prior to the enforcements of the provisions of the New Seismic Code of Greece in 1995, as was shown by the earthquake damage observations of Kalamata 1986, Pyrgos 1993, Kozani and Aigio 1995 and Athens 1999 (see Manos, 2011). Another particular structural deficiency is the “accidental” formation of short columns in RC framed structures again by building strong infill in various openings. These two structural deficiencies have been identified from past earthquake observations to be the main contributing factors of high-risk performances of RC multi-story structures in Greece which may seriously jeopardize the safety of multi-story structures in many Greek cities. It is fortunate that, as is shown at the right part of figure 8, temporary wooden supports were added in the case of this building in Samos in order to ascertain, up to a degree, its structural stability during the aftershock earthquake sequence in Samos. This was shown to be critical in many post-earthquake observations (see Manos, 2011).

Observed structural damage at the Greek island of Samos

As already mentioned, the reinforced concrete building in Samos designed even with the old seismic code provisions did not sustain serious structural damage, with a few exceptions. The damage to be reported here focuses on old structures. Severe structural damage was sustained by numerous Christian Greek Orthodox churches (Manos and Kozikopoulos, 2015; Manos, Soulis, Karamitsios, 2012; Manos and Karamitsios, 2013; Manos, 2016; Manos, Kotoulas and Kozikopoulos, 2019; Manos and Kotoulas, 2019).

The most spectacular structural damage of this type occurred at the church of Koimiseos Tis Theotokou in Karlovasi-Samos. This church is depicted in figure 9 prior to this earthquake. It is a three-nave cruciform “Basilica” with a central dome, built in 1898, and it serves as the Cathedral for the city of Karlovasi. According to information, as yet unverified, this church was subjected to at least two strong earthquake ground motions (1904 and 1954). It has a considerable height in order to accommodate the women’ quarter as a second story at the West part of the church. The central

Figure 8. Shear failure of columns at the ground floor “soft” story of RC multi-story buildings at Samos island (ETAM report Nov. 2020 (Preliminary report, November 2020))

semi-spherical dome is supported by a cylindrical tympanum with numerous windows which remained undamaged. The central nave extends longitudinally in the East-West direction from the central dome by semi-cylindrical domes covered by a wooden roof with tiles and at their two East and West ends by ¼ spherical parts. Similarly, the transept extends in the North-South transverse direction from the central dome with semi-cylindrical domes covered by a wooden roof with tiles and at their two North and South ends by ¼ spherical parts. Internally, the three naves are supported by colonnades formed by a series of slender columns rising from the floor to the level of the base of the central spherical dome and the adjacent semi-cylindrical domes. The following observations can be made from the structural damage observed at this church, depicted in figures 9, 10, 11, 14 and 15.

1. The structural system of the church of Agiou Konstantinou kai Elenis at Kozani (Figure 11) is similar to the one depicted here. This church was studied extensively by Manos (1997) and Soulis and Manos (2019) in order to understand the mechanisms that generated the structural damage it sustained during the 1995 earthquake sequence and propose a retrofitting scheme that was constructed in order to strengthen its earthquake resistance (Manos et.al., 1997; Soulis and Manos, 2019; Manos, Soulis, Diagouma, 2008). It was shown from this investigation that large seismic forces are generated by the considerable masses of the spherical and cylindrical domes that form the superstructure and the combination of relevant eigen-modes excited by the characteristics of the horizontal components of the seismic ground motion. These seismic forces are generated at considerable height and are resisted mainly by the peripheral stiff unreinforced masonry walls whereas the internal colonnades provide minimal resistance to these horizontal seismic forces due to their relative flexibility.

Figure 9. The church of Koimiseos Tis Theotokou (Assumption of Virgin Mary) in Karlovasi the Cathedral church of Samos, prior to the 30th of October 2020 earthquake

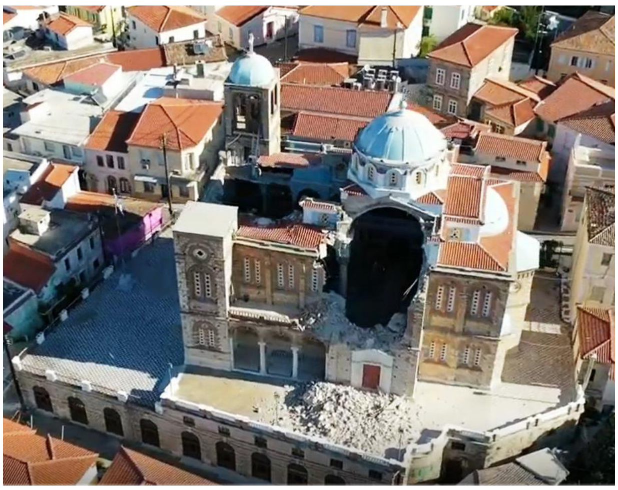

Figure 10. The collapsed parts of the domes at the West and North part of this church

2. The seismic resistance of these walls is reduced by the openings (doors or windows) as well as by the way they are constructed in terms of materials and construction techniques. Figures 9 and 10 indicate that these are constructed with unreinforced masonry. An extensive research of the structural damage of unreinforced masonry peripheral walls forming numerous churches at the Greek island of Kefalonia is described in summary form in references (Manos and Kozikopoulos, 2015; Manos, Kotoulas and Kozikopoulos, 2019; Manos and Kotoulas, 2019). This investigation combined the results of 3-D numerical simulations and assumed failure criteria to demonstrate the validity of utilizing realistic limit-state scenarios in order to explain successfully the observed damage. These limit-state scenarios include mainly shear or diagonal in-plane modes of failure or out-of-plane bending modes of failure. Such typical damage is depicted in figure 15.

3. The partial collapse of the superstructure must be attributed to such combined in-plane and out-of-plane modes of failure of the peripheral walls. This partial collapse causes the loss of support for

Figure 11. The collapsed parts of the domes at the West and North part of the church

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the superstructure domes that are collapsing next in a sequential order. This is clearly indicated by figure 10 depicting the collapse of part of the Southern part of the transept by the out-of-plane collapse of the peripheral wall and the corresponding part of the superstructure. This is also indicated up to a point in figure 13. However, this time the partial collapse of the upper part of the peripheral wall was not followed by the sequential collapse of the supported superstructure.

4. The mechanism of the collapsed Western part of the central nave shown in figures 10 and 11 is more complicated. This may be due to the role of the ¼ spherical domes that bridges the space between the Western semi-cylindrical dome with the roof next to the central dome and the Western peripheral wall. This ¼ spherical dome is followed by a semi-cylindrical dome till it reaches the somehow elevated semi-cylindrical dome covered by the wooden roof with the tiles. The actual support conditions of this ¼ spherical dome are not known. Moreover, unknown are also the connection conditions of this part of the superstructure to either the adjacent dome or to this peripheral West wall. Figure 14 suggests that both these support and connection conditions failed and contributed to the loss of support of this part which, because of its considerable weight, could not be supported and this led to its collapse.

5. It is of interest to observe that a similar ¼ semispherical dome forms the cover of the East part of the central nave over the sanctuary. This part remained in its place despite its being damaged. This again can be partly explained because the East ¼ semispherical dome is not extended by an additional semi-cylindrical dome till it reaches the somehow elevated semi-cylindrical dome covered by the wooden roof with the tiles, as was described before for the Western part. Moreover, this part of the superstructure is supported by the East peripheral wall that is formed partly by the presence of an apse. It was demonstrated by previous research that the presence of such an apse provides considerable out-of-plane stiffness to a planar wall. Figure 15 depicts this part of the wall which, although heavily damaged, did not collapse.

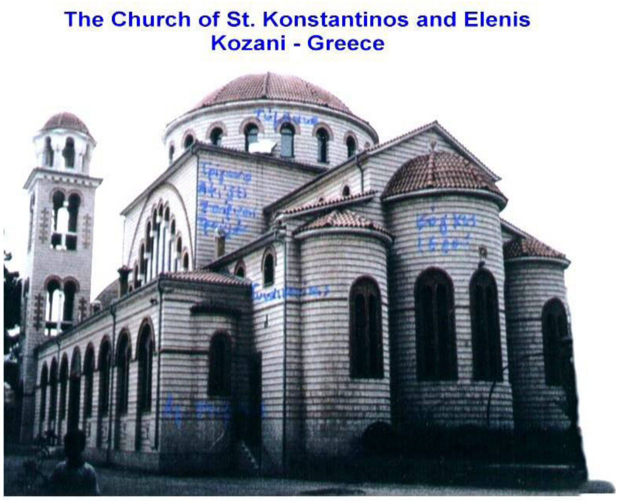

Figure 12. The church of St. Konstantinos and Eleni damaged by the 1999 Kozani-Greece earthquake (Manos et.al., 1997; Soulis and Manos, 2019)

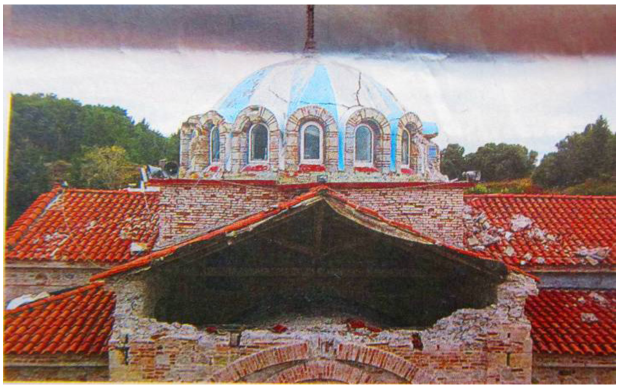

Figure 13. The church of Virgin Mary at the village of Konteika Samos island built in the 19th century. This church is again of the cruciform typology with a central spherical dome that sustained structural damage of the peripheral wall of typical morphology (Manos, Soulis, Diagouma, 2008)

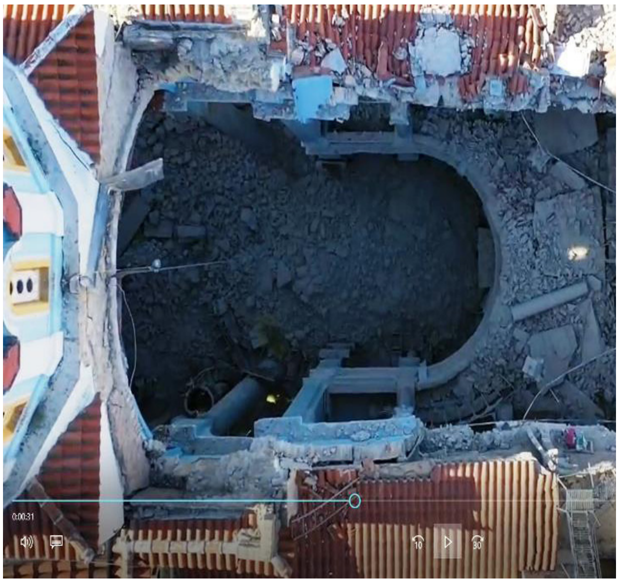

Figure 14. View of the collapsed Western part of the central nave

Figure 15. Damage of the Eastern peripheral wall with the Apse. Members of the emergency group salvaging the holy cross from the interior of this church

6. Another point to be made is related to the Northern part of the transept which did not collapse. Thus, its performance is different from that of the Southern part despite the fact that is almost of the same geometry. Any differences on the support and connection conditions between the two parts are not known. Moreover, unknown are any differences between the North and the South peripheral walls. One observation that must be underlined here is the foundation conditions of this church. As can be seen in figure 9 this church is built on a sloping hill in a way that a large portion of the structure extended from the longitudinal East-West axis of symmetry towards the South, rises from the low part of the slope. This leaves enough space under the floor level of the church for the formation of an extra story mainly at its Southern portion. It is not known how the flexibility of this story has influenced the dynamics of the whole system. Moreover, it must be investigated further whether the deformability of the supports of this part of the structure combined with the vertical component of the ground seismic motion contributed to the collapse of the Southern and not the Northern part of the superstructure. Figure 16 depicts the partial collapse of the church of St. Giorgio at L'Aquila-Italy (Croci, 1998; Limoge Schraen, Giry, Desprez, Ragueneau, 2015; Cerone, Viscovic, Carriero, Sabbadini, Capparela, 2001; Lagomarsino, 2011; Modena et.al., 2010). Certain similarities can be seen between the observations made here in figures 10, 11 and 14 and the L'Aquila damage depicted in figure 16.

Figure 16. The church of St. Giorgio damaged by the 6th of April 2009, L'Aquila-Italy, earthquake sequence (top and bottom)

7. Factors that may have contributed to this earthquake performance of this church are ones connected to past earthquake events and the type of maintenance works that were performed. It was already reported that two strong earthquakes occurred at Samos island in 1904 and 1954 with this church already built. Currently, temporary supports have been erected to prohibit any further collapse. Moreover, the reconstruction of this church was ensured by a recent visit at this site of the Prime Minister of Greece.

Old masonry buildings under conservation status

Figure 18 depicts the structural damage of low-rise buildings at Vathi sustained by the Samos earthquake of 30th of October 2020. Many of such buildings located at various urban areas in Greece are under special conservation status due to architectural features or historical significance. However, many of these buildings are left without either serious maintenance or the necessary

Figure 17. Typical damage to the peripheral masonry walls of "Basilica" churches from earthquake activity in Greece. At the top, a "Basilica" church at the village of Nisi from the Patras-Pyrgos earthquake of 8th June, 2008. At the bottom, a "Basilica" church at Karlovasi damaged from the Samos earthquake of 2020 (Manos and Kozikopoulos, 2015; Manos, Soulis, Karamitsios, 2012; Manos and Karamitsios, 2013; Manos, 2016; Manos, Kotoulas and Kozikopoulos, 2019; Manos and Kotoulas, 2019)

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retrofitting measures to upgrade their earthquake resistance. Moreover, a long-term debate has been taking place of the level of upgrading necessary, of the retrofitting techniques that could be allowed in such an effort and on who is going to pay for this retrofitting cost.

The conservation status when legislated is not accompanied with the necessary funds for the retrofitting effort. At the same time, when these building are privately owned the owners are very reluctant to undertake such a retrofitting cost because a different form of development involving the demolition of the old structure and the rebuilding of a new structure on the same premises is a much more profitable operation. This is especially true in places whereby the development from tourism changed drastically the financial activity and prospects in many Greek localities. To be found in many Greek islands as well as at the old part of city-centers in many Greek cities. In such instances the owners are expecting that an extreme event, e.g. a strong earthquake activity, will result in the destruction of such an old building resolving in this way on their benefit the conservation status burden when the severe structural damage and partial collapse will be the final result of such an extreme event. Many times, these buildings that are under conservation status change ownership and become the property of either the municipality or of a public agency. This is the case of the buildings shown in figures 19 and 22.

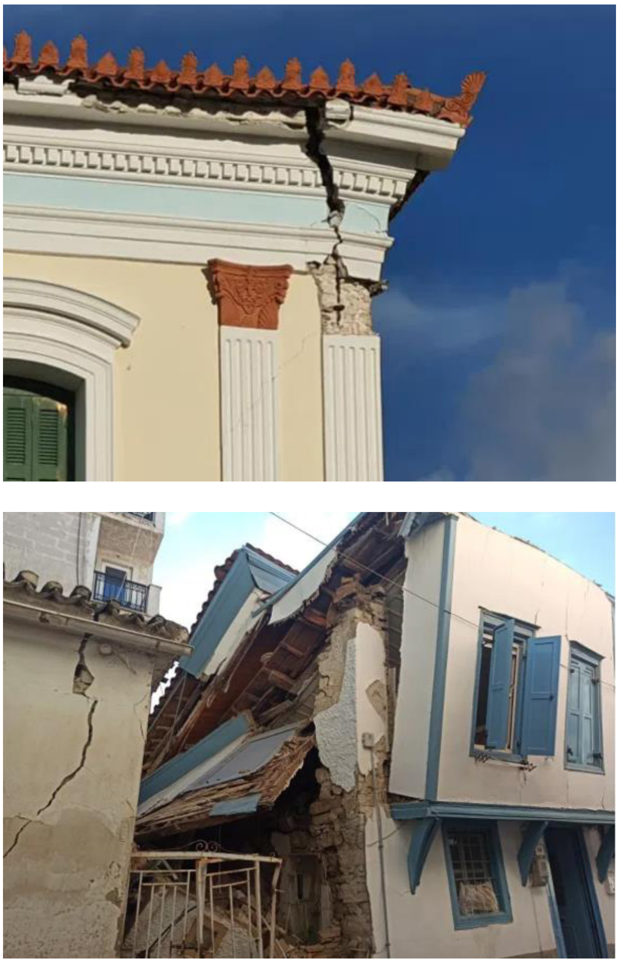

Figure 18. Damage of old low-story buildings at Vathi. In need of preservation because of particular architectural features

Figure 19. Old industrial buildings under conservation status

The buildings in figure 19 are old industrial buildings, named “Tampakika” being under conservation status in Karlovasi at Samos island. Initially, these buildings were built at the end of the 19th century, near the sea-shore of Karlovasi, as factories for the processing of leather. This activity was very prominent from 1880 till the beginning of World War II. After this, the leather processing in this part of the island started to decline having as a result for these buildings to be abandoned after few decades. Many old buildings were listed as part of cultural heritage under conservation status at the beginning of 1980. However, the effort for their maintenance and retrofitting has been, as explained before, relatively slow

A considerable number of the buildings depicted in figure 19 changed ownership and became part of the University of Aegean at the beginning of the 21st century. Recently in 2019 an agreement was signed between the Prefecture of Northern Aegean the Municipality of Samos and the University of Aegean, with the Technical University of Athens serving as technical consultant, to promote the retrofitting effort for these buildings. Unfortunately, the 30th of October Samos earthquake caused considerable structural damage to numerous buildings of this particular type, as shown in figure 22. The observed damage was of the typical form of loss of support and collapse of the wooden roof accompanied by the partial out-of-plane collapse of the long peripheral walls. The location of these buildings is shown in figure 21.

Old unreinforced masonry buildings that pose a potential threat for injuries

A final topic of interest is the partial collapse of low-story unreinforced masonry buildings causing the deadly injury of two young teenagers at the city of Vathi. Despite the low-rise of these buildings, the deadly event was caused by the considerable weight of the falling parts and the narrow streets in the old part of the city that inhibit any escape. This is depicted in figures 23 and 24. As a result, a special legislation is on the making for allowing the technical services of each municipality to order the demolition of old properties that are left without the proper maintenance of their owners and can be judged as representing a possible risk by partial collapse in the eventuality of a future earthquake. Again, for this type of problems the issue is partly technical and partly social-economic. The new legislature provides that the demolition cost will be initially paid by the municipality and then claimed back to be paid by the owners.

Numerical simulation of the earthquake behaviour of the old industrial buildings at Karlovasi

In this section, a summary of numerical predictions are presented focusing on the dynamic and earthquake response of a typical industrial building of the typology depicted in figures 19 and 22. The response of this type of structures is dominated by certain response mechanisms that

Figure 20. An old industrial building (The Markou Mill processing wheat to produce flour) in Veria-Greece, which now houses the Museum of Byzantine art of this city

can be characterized as "global". These mechanisms include a) the connection of the wooden roof to the masonry walls b) the interconnection of the masonry walls at the corners and c) the potential of partial uplifting at the foundation due to tensile forces arising from excessive overturning moment response and uneven foundation settlements (Manos and Kozikopoulos, 2015; Manos, Kotoulas and Kozikopoulos, 2019). All these mechanisms are non-linear in nature and it is many times difficult to quantify them in order to include their influence in realistic numerical approximations. In what follows, an attempt is made to investigate the dynamic and earthquake response for a typical structure representing one of those old industrial building. In figure 25 the recordings of the earthquake ground motion, in terms of ground acceleration, velocity

Figure 21. Map indicating the location of the damaged old industrial buildings in Karlovasi - Samos

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Figure 22. The partial collapse of one of the industrial buildings at the seafront of Karlovasi

Figure 23. The partial collapse of old unreinforced masonry structures at Vathi that caused the death of two young teenagers

Samos Earthquake 30-10-2020, Damage from the main event at the city of Vathi, capital of the island of Samos. The most severe structural damage was related to unreinforced low-rise masonry buildings. Some of these buildings were left unoccupied and unmaintained for a long period

Figure 24. The partial collapse of old unreinforced masonry structures at Vathi that caused the death of two young teenagers

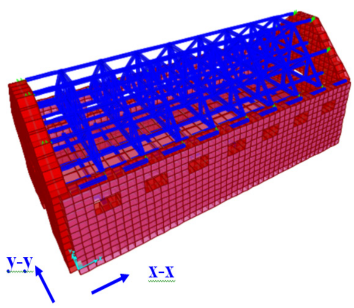

Figure 26. The numerical model of a typical industrial building of unreinforced masonry damaged by the 30th of October Samos earthquake (see figures 19 and 20)

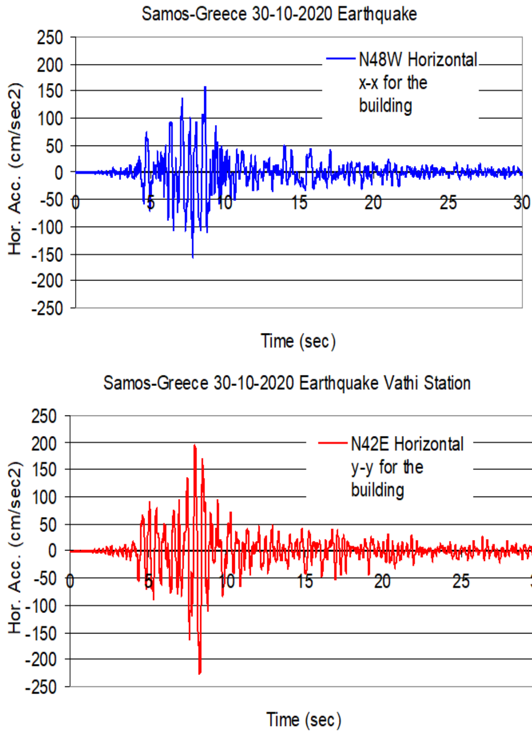

Figure 25. The recorded ground motion in the two horizontal directions by an instrument managed by the Institute of Earthquake Engineering and Engineering Seismology (ITSAK, see report (Preliminary report, October 2020; Preliminary report, November 2020)

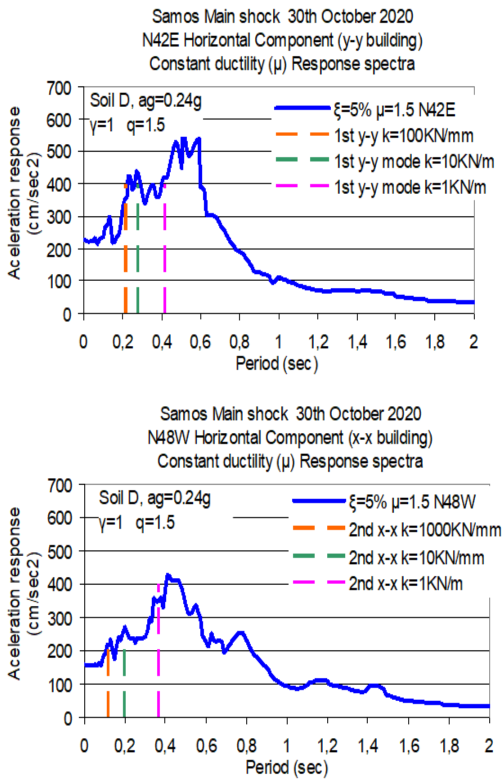

Figure 27. Acceleration response spectral curves for the two horizontal components of the earthquake ground motion recorded at Vathi during the 30th of October main event (see figure 25)

and displacement in the two horizontal directions are shown. Due to the location of the epicenter, the same epicentral distance of both the city of Vathi and the city of Karlovasi from the epicenter (see figures 1, 2, 3 and 21) and due to the generating mechanism of this earthquake that followed the almost East-West fault line, as can be seen from the aftershock sequence it can be reasonably assumed that the strong motion characteristics at Karlovasi would be quite similar to those of the recorded strong motion at Vathi.

The numerical model of this analysed industrial building with its wooden roof is depicted in figure 26. The wooden roof elements are connected with the masonry peripheral walls without transferring any bending moments. The stiffness of this connection is a parameter that is varied in this investigation. Summary results form various numerical dynamic spectral analyses are presented here. Each dynamic analysis is carried out based on the response spectral curves derived from the recording of the earthquake motion in the two horizontal directions at Vathi (Fig. 25). It was discussed, that this represents a realistic assumption. The corresponding spectral curves are depicted in figure 27. The response spectral curves in these figures were derived assuming a behaviour factor value equal to q=1.5 that is appropriate for unreinforced masonry structures.

The two-fundamental translational eigen-modes, derived from this numerical model, are depicted in figures 28 and 29. Figure 28 depicts the 1st translational mode in the direction y-y. The outstanding response in this mode is the out-of-plane response of the two longitudinal peripheral walls parallel to the x-x axis. Similarly, figure 29 depicts the 2nd translational mode in the direction x-x. The outstanding response in this mode is the out of plane response of the peripheral walls parallel to the y-y axis. The eigen-period values of these 1st and 2nd translational modes are shown in figure 27 depicting the response spectral curves in the N42E and N48W horizontal directions, respectively. A range of such eigen-period values are plotted in these two plots. The variation of these eigen-period values resulted from the variation of the stiffness of the connection of the wooden roof elements to the masonry peripheral walls, as indicated in these plots.

Figure 30 depicts the maximum displacement response for the load combination Dead + 0,3 ResSpec x-x + ResSpec y-y**.** As expected, the peak out-of-plane Uy displacement at the top of the longitudinal peripheral walls (the ones parallel to the x-x direction) become larger as the stiffness of the wooden roof with the masonry peripheral walls becomes smaller. The results of this relatively simplified numerical analyses explain, up to a degree, the observed damage sustained by these old industrial buildings during the recent 30th of October, Samos earthquake (Figure 22).

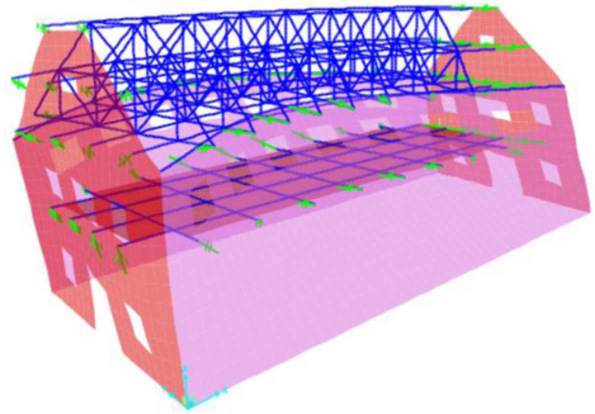

Figure 28. 1st translational eigen-mode. Out of plane response of the peripheral walls parallel to the y-y axis

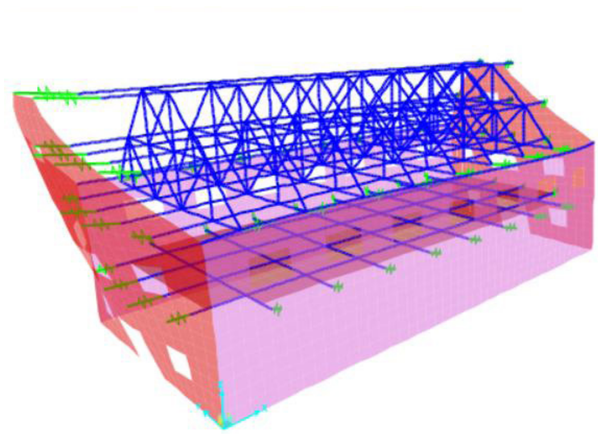

Figure 29. 2nd translational eigen-mode. Out of plane response of the peripheral walls parallel to the x-x axis

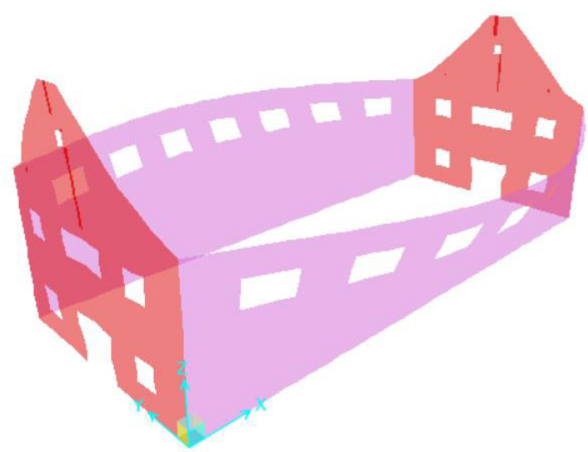

Figure 30. Displacement response from the load combination Dead + 0,3 ResSpec x-x + ResSpec y-y

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Conclusions

- The recent earthquake sequence in the Greek island of Samos gave the opportunity of assessing the earthquake performance of various types of structure in Greece. It can be stated that the enforcement in 1995 of the "New Greek Seismic Code" together with the provisions of the Euro-Codes has substantially increased the safety level of structures against earthquakes. A similar successful effort has been made through various educational channels for upgrading the relevant design and construction practices of professionals as well as the relevant knowledge of the general public in earthquake preparedness measures. A significant expansion of the strong motion network of accelerographs that covers the whole of Greece provides very important information on the characteristics of the earthquake strong ground motion that is very useful in assessing the consequences of the intense earthquake activity to the built environment. The relevant data base is enriched with valuable information on the characteristics of the earthquake strong ground motion that is very useful to designers and contractors.

- For RC multi-story buildings which were constructed prior to the enforcement of the New Greek Seismic Code Provisions (before 1995) certain "structural deficiencies" have long been identified that pose high risk towards seismic safety. One particular "structural deficiency" is that of a "soft" ground floor for RC multi-story buildings resulting in amplified shear force demands for the ground floor columns at an amplitude that can not be met by the corresponding shear capacity due to the shear reinforcing detailing of these ground floor columns according to the old code provisions. Another similar structural deficiency is the "accidental" formation of short columns in RC framed structures once again by building strong infill in various openings. These non-ductile response "structural deficiencies" combined with irregularities in plan and elevation as well as with strong earthquake ground motions, which often lead to demands exceeding the corresponding demands assumed in design, result in structural damage that caused in the past serious fatalities, fortunately in small numbers. A specific code with provisions focusing on the assessment of the vulnerability of such structures as well as on provisions relevant to the structural upgrading has been published for some time. However, the retrofitting effort is colossal as the buildings in this category are numerous (Organization of Earthquake Planning and Protection of Greece (OASP), 2001; Manos and Katakalos, 2013).

- Another high seismic risk category includes old structures under conservation status including cultural heritage structures. A large number of such structures are relatively old Christian Greek Orthodox churches, built with unreinforced masonry, which have sustained heavy structural damage during the last 40 years. They represent special cases because their structural system is more complex than that of ordinary buildings. Similar difficulty exists in assessing for such structures the capacity of their structural members as well as in applying acceptable retrofitting solutions that respect the principles of compatibility and reversibility. Moreover, various social-economic complications render the various retrofitting attempts even more difficult and time-consuming. This study tries to highlight some of these issues and to present some of the numerical tools to deal with such structures.

- Another source of seismic risk that can result in human loss was highlighted by this earthquake event. It is generated by old and weak unreinforced masonry structures which are left un-occupied and not maintained by their owners due to various social-economic non-incentives and complications. Legislation is currently proposed to tackle this problem. Another group of high seismic risk buildings are the ones that are not designed by earthquake resistant design provisions in localities that are far away from the authorities. Additional legislation, currently enforced, aims to reduce the seismic risk arising from this group of buildings.

- Numerical tools combined with realistic measurements of the seismic forces generated by a strong earthquake ground motions can be utilized to explain the observed structural damage. They can also be utilized in the subsequent retrofitting effort.

To the memory of Nikolaos Simos, PhD, PE, Senior Scientist Emeritus\ Brookhaven National Laboratory, U.S.A.

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NEW JEWISH STYLE IN LVIV ARCHITECTURE: THE HISTORIC TRANSFORMATION IN THE URBAN SPACE

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Abstract
Introduction: The phenomenon of expressing national identity in architecture is manifested in many countries and cities. In this article, it is considered in the context of Lviv with the main focus on Jewish architects. **Purpose of the study:** We are planning to study the process of the emergence of a new Jewish style in the architecture of Lviv from the mid-19th century to the first decades of the 20th century in the context of urban development, and consider the formation of a characteristic art language, together with the corresponding symbolic elements of décor. **Methods:** We use a comprehensive art approach, which involves the method of systematization for material processing, comparison and synthesis. In the course of the study, we applied comparative analysis, as well as elements of systematic analysis of the Jewish architecture evolution. **Results and discussion:** We conclude that the architects used several strategies and theories to express Jewish cultural identity in their works, in particular, neo-romantic transformations of medieval, Renaissance and Oriental architecture, rethinking in the spirit of Art Nouveau of the Neo-Moorish style, incorporation of old regional architecture motifs, applying decor saturated with Jewish symbols.

Keywords
Lviv, Jewish architects, urban evolution, cultural identity, new national Jewish style.

Introduction

Currently, the issues of cultural globalization, and, on the contrary, the issues of identity and national styles in architecture are among the most frequently discussed in the artistic environment (Abel, 1997; Lefaivre and Tzonis, 2003; Watson and Bentley, 2007). This also applies to the issue of Jewish cultural identity and specific Jewish art style (Aleksandrowicz-Pędich and Pakier, 2012; Bedoir, 2004; Coenen Snyder, 2013; Holzer, 1999; Klein, 2005–2007; Rabin, 1996; Sachs and Van Voolen, 2004; Shapira, 2016). To what extent one can classify a piece of architecture as "Jewish" is still open to debate.

All over Europe, as well as in Lviv, these issues became relevant as early as in the middle of the 19th century, and at the turn of the 19th and 20th centuries, they were a matter of great concern to Jewish artists.

The historical, political, economic, and socio-cultural environment was such that Lviv developed as a unique city, with an architectural stratigraphy, which can clearly reveal various stylistic blocks. However, since the mid-19th century, there was a search for a special, national Jewish style, especially in religious buildings. Due to the fact that the historical research of architecture in the Lviv region was unsystematic, it is not a surprise that a comprehensive view of the Jewish architecture evolution has not been formed. To resolve issues related to the study and protection of these monuments, it is essential to reveal particular patterns in the formation of Jewish architecture.

Methods

Due to the method of aesthetic and critical analysis of the art, we show some peculiarities of the formal structure of buildings, interaction between the means of artistic expression and the conceptual system of some architects. We reveal and compare the historical levels in the development of the works, their technological and stylistic changes in time, and study the relationships between various artistic techniques and plastic modeling options at different stages of architectural forms' creation. Throughout the study, we use multiple resources: theoretical works of architectural scholars; information in local newspapers in addition to archival documents.

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Results and discussion

1. In the Habsburg Empire: the beginning of the search for a national style

Since the mid-19th century, after the revolutionary events in 1848 (Spring of Nations), historicism began to develop actively in Jewish architecture in Lviv as a complex of different retrospective trends, i.e. "neo-styles" (Revival architectural styles) (Van Pelt and Westfall, 1991). For the Jewish elite of the city, it was especially important to emphasize that the synagogues should occupy an honorary place in the city center and be built in the latest fashion blending well with the new architectural style of the city. Adapting the latest architectural styles to the needs of the community, the Jews seemed to show their readiness for full emancipation.

For instance, in 1856, the old building of the Sykstuska Synagogue was demolished and rebuilt in 1857–1859, together with the Beth Hamidrash, with features of Rundbogenstil and Romanesque Revival styles, to a design by Wilhelm Schmidt, and in 1864–1867, architect Emanuel Gall added a single-story northern wing to the Beth Hamidrash) (Fig. 1).

The façade of the Beth Hamidrash in the Romanesque Revival style acquired large arched windows, with reliefs depicting the Tablets of Stone of Moses, placed in between them at the level of the second floor. In 1876, architect Josef Engel Senior developed a design of a women's *mikveh* at the Sykstuska Synagogue, located at 22 Sykstuska Street (Fig. 2).

For the first time in Lviv, distinctive Moorish motifs were used in the decoration of the façade, windows and doors (State Archives of the Lviv Region, Collection 2, Register 1, File 313, pp. 22, 36–42, 96–98, 122–123, 144–155; File 3018, p. 29). This new Orientalism indicated the readiness of the then Jewish community to engage in an open inter-confessional dialogue, and explore a new synthesis of Jewish culture with the surrounding Christianity. The impetus for the development of the transformed Moorish Revival style in the Jewish architecture of Lviv was brought about by the villa of Louis Pereira-Arnstein, built by Ludwig Förster in Königstetten (1849), and synagogues of his creation built in 1854–1859 in Budapest (Dohány Street) and Vienna (Leopoldstädter Tempel, destroyed in 1938) (Kalmar, 2001; Klein, 2006; Kravtsov, 2016a).

2. Construction boom and national revival

After the final lifting of restrictions on education, business, accommodation, and real estate purchasing in 1867, the number of Jews in Lviv increased significantly. They settled in almost every area of Lviv. During the Historicism period, an increase in the Jewish population in the city led to very intensive development in housing construction of various types of buildings. These were commissioned by members of the new Jewish elite (Buszko, 1999; Holzer, 1999).

The architecture of such villas and mansions, built for Jewish owners since the late 19th century, amazes with the dynamics of shapes and a wide range of design, composition, and stylistic solutions. Even with such diversity, it is, nevertheless, possible to identify common specific design principles based on rationalism and convenience, which were not tarnished by non-standard plans. Since after 1867 Jews were allowed to own land, the nouveaux riches began to invest in residential tenement houses. They were actively constructed in the 1870–1890s, often forming street ensembles. In terms of style, various Neo-Renaissance interpretations dominated: Italian, French, and sometimes German Neo-Renaissance. In the late 1880s, Neo-Renaissance motifs began to be increasingly linked to Neo-Baroque, and eventually, in the 1890s, the latter became the absolute dominant style in housing. At the same time, symbols related to Jewish history and tradition were introduced into the decor of the facades of buildings in common European neo-styles.

Figure 1. Sykstuska Synagogue. 1857–1867. Photo of 1916. Austrian State Archives, Vienna

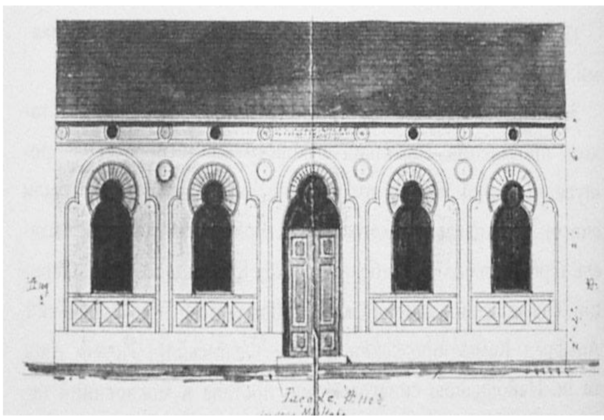

Figure 2. Design of a women's *mikveh* at the Sykstuska Synagogue. 1876. State Archives of the Lviv Region

At the turn of the 19th and 20th centuries, the streets leading to the railway station underwent the most active development, especially Gródecka (Horodots'ka) Street and its side streets, with a new commercial area being developed around them. A large number of Jewish families settled in this district, following which synagogues were built in the Rundbogenstil and Moorish Revival style. The first of them, emerging around 1882–1890, was the synagogue of the Agudas Achim (Association of Brothers) Society at 15 J. Bem (today's Yaroslav Mudry) Street; it was housed in a residential building built by Jan Karasiński in 1882. The Agudas Schloma (Solomon's Association) synagogue appeared at 39 J. Bem in 1899–1902, built to a design by architect Salomon Riemer (State Archives of the Lviv Region, Collection 2, Register 3, File 1479, pp. 3, 4, 79). In 1901, the Gall-Eid (Wheel of Testimony) synagogue was built at 14 Queen Jadwiga (today's Marko Vovchok Street) at the expense of Jakob Gall and presumably to a design by Maurycy Gall. It was erected in honor of Emanuel Gall, an architect and Commander of the Jewish Guard in the Academic Legion in Lviv during the Spring of Nations in 1848, not only named after him but also including a direct reference to the Book of Genesis (Gen. 31:48).

In the second half of the 19th and early 20th centuries, Bem Street was mainly built up with Jewish buildings, in the same way as the other side streets of Horodots'ka Street. Tenement houses in Horodots'ka Street were commissioned by Jewish owners in various styles. We should especially note building No. 117 (building of Mojżesz Fisher and Łazarus Sandler, architects Edward Skawiński and Henryk Orlean, 1911) featuring modernized Romanesque characteristics with elements of the Jewish style that emerged from the Moorish Revival style. In the second half of the 19th century and the beginning of the 20th century, at the time of its flourishing during the final decades of the Austrian Empire, the Jewish community in Lviv acquired numerous synagogues, prayer houses, mikvehs, schools, libraries, printing houses, editorial offices of newspapers and magazines, shelters, hospitals, a theatre providing performances in Yiddish (opened by J. B. Gimpel in 1889), banking and commercial buildings.

In Bernstein (today's Sholem Aleichem) Street, two public buildings were built in the Neo-Renaissance and Neo-Baroque styles (with elements of the "Jewish Art Nouveau" in their interior design): the House of the Association of Lviv craftsmen Jad Haruzim ("Skillful Hand", architect M. Silberstein, 1896) and the House of the Board of the Jewish Religious Community — Qahal (1899, architects Antoni Rudolf Fleischl and Maurycy Gall).

In 1899–1902, the Jewish Hospital, founded by M. Lazarus, was built at 8 Rappoport Street (Fig. 3) — this is the only building that has survived in Lviv, being totally arranged in modernized motifs of Oriental architecture (Kravtsov, 2016b).

The hospital was built by Ivan Levynsky to a design by Kazimierz Mokłowski, with avant-corps, decorated horizontal bands of yellow and red bricks, openwork balustrades of attics with dentils, and a large bulbous dome, covered with tiles of four colors. Combined Moorish and Jewish motifs dominated in the bright paintings on the walls of the entrance passage, created by the Fleck brothers. The stylistics of the hospital was influenced by the architecture of the Reformer synagogue in Chernivtsi, built by Julian Zachariewicz in 1873–1877. As Zachariewicz himself noted in an article in the Viennese architectural journal *Allgemeine Bauzeitung*, he designed the location of the altar, Aron-Kodesch, according to the principles of Judaism. The exterior of the shrine was also meant to answer the purpose. "It was necessary for this building to look at least like a Christian church. The Moorish style is best suited for this, which is an expression of the feelings and spirit of the Moses religion", the architect emphasized (Zachariewicz, 1882).

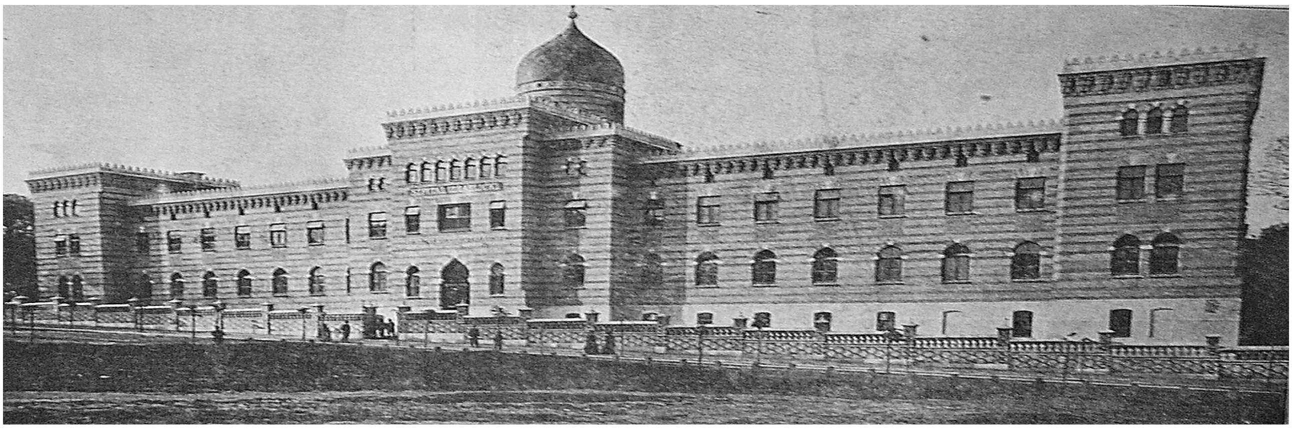

Figure 3. The Jewish Hospital. 1899–1902. Photo by Marek Münz, 1904, from Nowości ilustrowane, 8 (1904), p. 4

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The author of the Jewish hospital, Kazimierz Mokłowski, developed the theory of the new binational Polish-Ukrainian “Carpathian” style in his book “Folk Art in Poland” (1903). There he also explored the Galician wooden and nine-bay masonry synagogues of the 17th–18th century but did not see the possibility of creating a new Jewish national style based on their study.

These construction activities accompanied the beginning of the Jewish National Revival. Jewish construction in Lviv, throughout 1860–1914, took place within the framework of the economic, social, political, and specifically the public life of the city. Since 1869, when the *Shomer Israel* (Israel’s Guardian) Association emerged, together with its *Der Israelit* weekly publication, assimilation tendencies among the Lviv Jews escalated, at first following a pro-German cultural orientation, and then a pro-Polish one, after the creation of the *Agudas Achim* (Association of Brothers) Society in 1883. At the same time, in 1880–1890s, Palestinophil and Zionist organizations were established, initiated in particular by writer and sculptor Alfred Nossig (Mendelsohn, 1971); a socialist movement was initiated by Herman Diamand. Lviv became a major center of Jewish education, book printing, scientific thought, literature, and art.

3. The emergence of new forms: Art Nouveau and the search for a new Jewish style

Religious and public buildings were of particular importance in the process of the emergence of new forms in Jewish architecture in Lviv in 1897–1918.

At the turn of the 19th–20th centuries in Lviv, as well as throughout Europe, one of the most important components of the artistic process was the study of the national heritage, folk art and the desire of art theorists and artists to create on this basis a new, original style inherent in each nation (Bowe, 1993). Polish and Ukrainian architects and artists of Lviv have successfully carried out such attempts since 1880 (Biryulov, 2001). In the Jewish environment of Lviv, similar actions (in particular, those associated with exhibiting a collection of Jewish art monuments at the General Regional Exhibition of 1894) had an obvious ideological and political aspect. The birth and spread of the ideas of Zionism (Mendelsohn, 1971; Wierzbieniec, 2005), “oriental exclusivity” in Lviv found a response among artists and architects who strove to create an original Jewish style. Many of the Zionists in Lviv proclaimed their Oriental separateness with pride. There was a “Semitic” stream in Zionism, whose chief ideological spokesman was Martin Buber, who came from a famous Lviv family.

The Moorish-Revival architectural style matched well with the Zionist ideology. From the 1870s to the end of the 19th century, many synagogues were built in this style in the USA, Great Britain, Italy, Germany, Austria-Hungary (Klein, 2006; Kravtsov, 2016a; Wischnitzer, 1964). The ideals of Orientalist Zionism and of Moorish-Revival style synagogue architecture were joined in the work of Viennese architect Wilhelm Stiassny (Jarassé, 2001; Kravtsov, 2016a; Krinsky, 1985;), who was very famous in Galicia (in particular, in 1895 he built the Tempel synagogue in Stanislawów (now Ivano-Frankivsk; the synagogue has not survived). His Jerusalem or “Jubilee” synagogue in Prague (1906) was already the work of a new Jewish national style, in the synthesis of Art Nouveau and Neo-Moorish direction. Contemporaries and followers of Stiassny in Austria-Hungary, e.g. Lipót Baumhorn and younger Viennese architects also successfully worked in this direction, including creating secular buildings (Prokop, 2016).

At the turn of the 19th and 20th centuries, the architects of Lviv’s synagogues retained the traditional two-level structure with a prayer room and a gallery, as well as an accent on Renaissance, Baroque, and Moorish forms. At the same time, attempts to shape the new Jewish artistic style as a branch of national romantic versions of Lviv Secession (Biryulov, 1999) were undertaken against that backdrop.

Julian Zachariewicz made his first attempt to create an architectural ensemble in the spirit of the “new Jewish style” in Lviv in 1894–1896 in his reconstruction project for the Progressive synagogue (Temple) in Rybny (Old Market) Square (Kravtsov, 2008). The idea of rebuilding the synagogue put forward by Zachariewicz was based on the concept of architect Charles Chipiez and archaeologist Georges Perrot. They proposed a combination of Assyrian, Phoenician, and Egyptian styles as a synthetic style of the Temple (Jarassé, 2001).

To get insight into Jewish ornamentation, in 1895 Zachariewicz collected traditional papercuts (*migzarot*), and in 1896 made sketches of the landscape of ancient Jerusalem for *The Crucifixion* panorama by Jan Styka, based on the study of ancient Jewish architecture.

After 1905, the acclaimed Józef Awin (1883–1942) was considered as the leading theoretician and architect of the Jewish version of Lviv Secession and “Post-Historicism”. At first, he was influenced by Art Nouveau in its German version (Jugendstil) but quickly began to form his own artistic worldview. As the basis of the new style, Awin announced taking on board the traditions of the ancient Eastern Galicia’s Jewish art, in particular, the architecture and decoration of the Galician wooden and nine-bay masonry synagogues of the 17th–18th centuries. Modern art history confirms that these old synagogues of the Polish-Lithuanian Commonwealth were an original stylistic phenomenon and deserved to become the basis for creating a new Jewish style (Krinsky, 1985; Piechotka and Piechotka, 2004; Wischnitzer, 1964). Awin took courageous steps to create a new architectural style based on an interpretation of the ancient Jewish and Near East art monuments. Awin expressed his views of the tasks faced by the new Jewish art in his articles “About our aesthetic culture” (1910), “About the style and character in architecture” (1911), and “About Herman Struck” (1913) (Kravtsov, 2010). The theoretical support for this search was subsequently provided by artist and art critic Oskar Aleksandrowicz.

Among Awin’s buildings, the Jewish students’ house stands out, i.e. the Academic House at 28 Saint Teresa Street (today’s Metropolitan Angelovych Street), designed in conjunction with A. Zachariewicz in 1908–1909. An even, flat façade in the geometric Art Nouveau style, with its only décor being stucco with a plaited motif and a frieze depicting the Star of David, accommodated the interiors (main conference room, parlors, dining room, library, etc.), which are now missing. In their embellishment — wall panels, furniture, lamps, paintings, and stained glass — one of the first attempts to consistently implement the foundations of the new Jewish style was made. “The building possesses a somewhat unusual style: an attempt to stylize old Jewish motifs sits well with the features of Secession”, noted one of the first visitors to the Academic House that was opened on 10 October 1909 (Żydowski dom akademicki, 1909).

In other works by Awin of that period — reconstruction projects for the synagogue at the Old Cemetery in Lviv (1909), and projects that were never accomplished: a competition design of the Herzliya Hebrew Gymnasium in Jaffa (now in Tel Aviv, 1908) (Awin, 1910), a project of a synagogue in a Polish town (1909), tombstone designs, and the Jewish House in Drohobych (1908–1914) (Bunikiewicz, 1910; Ornamentyka żydowska na wystawie wiosennej, 1914) — neat geometricity and rational planning were combined with the stylization of old Jewish manuscripts, textile, *matzevot* (tombstones), and ritual metal items (*menorahs*, etc.).

These ideas became even more pronounced in the tombstones that were created in 1925–1930 at the New Jewish Cemetery in Lviv (those of banker Samuel Horowitz, Head of the Galician Zionists Gerszon Zipper, Editor-in-Chief of Jewish magazines Abraham Korkis, journalist Mojżesz Frostig, journalist and President of the Galician Zionists Leon Reich), and also in the interior design of the Lviv branch of the B’nai B’rith Society (1927) (Biryulov, 2019).

Architects Henryk Hersch Salwer, Bruno Bauer, Ferdynand (Feiwel) Kassler, Leopold Reiss, and Albert (Aba) Kornblüth introduced the transformed motifs of old Jewish ornamentation into their works. Using high three-level attics, Artur Schleyen rebuilt the Hasidic Synagogue in 1904 at Bożnicza (today’s Sans’ka) Street. The building acquired the characteristics of modernized Late Renaissance and Mannerism, i.e. typical Lviv patterns of the late 16th and first decades of the 17th century.

The façade of the “Col Rina ve-Yeshua” (“Shouts of Joy and Salvation” — an allusion to *Song of Songs*, 118:15) Synagogue, also known as “Express”, at 49 Źródlana (Dzherel’na) Street by A. Kornblüth attracted attention with an engaging blend of Oriental Secession themes in the shapes and decorations of the portal, windows, attics with numerous Jewish symbols, all together creating an integral arrangement, becoming one of the first distinctive works of Jewish Art Nouveau (State Archives of the Lviv Region, Collection 2, Register 1, File 3127, pp. 2, 4–11, 21–27) (Fig. 4).

In 1911–1912, the Korte Shul Synagogue at 109–111 Żółkiewska (B. Khmelnytskyi) Street, belonging to the “Gomel Chesed” (“Good Deeds”) Society, was fundamentally rebuilt in the spirit of Jewish Art Nouveau, with a striking stylization of oriental motifs to a design by architect Bruno Bauer (the construction was supervised by A. Schleyen). The synagogue belonging to the “Beth-Lechem” (“Bread House”) Society at 8 Starozakonna (Mstyslav Udatnyi) Street occupied the first two floors of the house built in 1912. In search of a new distinctive Jewish style close to Art Nouveau, architect Jakub Scheller created a remarkable design for the main façade, combining Moorish Revival motifs with the Jewish symbolism. The façade was lavishly decorated, with dripstone of exquisite and finely detailed configurations, and with double dormers on the pediment, recreating the outlines of the Tablets of Stone (State Archives of the Lviv Region, Collection 2, Register 1, File 725; Registry 2, File 3827) (Fig. 5).

At the same time, i.e. in the early 20th century, synagogues appeared in different European countries, similar to the Prague Jubilee Synagogue of Stiassny, with an Art Nouveau interpretation of oriental or local traditional architecture, with characteristic ideological symbols in picturesque decoration. These were, e.g. the synagogues in Subotica (1902, architects M. Komor and D. Jakab), Malmö (1903, architect John Smedberg), the “Friedberger Anlage” synagogue in Frankfurt am Main (1904–1907; it has not survived), the Döbling Synagogue in Vienna (1907, Julius Wohlmuth), the Bournemouth Hebrew Congregation (1911), the Old Synagogue in Essen (1913, architect Edmund Körner), Kazinczy Street Synagogue in Budapest (1913, Sándor and Béla Löffler).

Awin and other Jewish architects of Lviv were obviously aware of the search for a new national style

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in the early 20th century in Palestine. Expressing a romanticist tendency and the ideas of Art Nouveau style, the architects identified the "Oriental", especially the Palestinian vernacular culture, as a repository of the authentic but lost Hebraic identity. The Herzliya Hebrew Gymnasium in Jaffa (now in Tel Aviv, 1909, designed by Joseph Barsky) and the Technion — the Israel Institute of Technology in Haifa (architect Alexander Baerwald, 1910–1924) — are some of the brightest examples of the Palestinian version of Art Nouveau, which required the creation of a national style with an appeal to regional traditions (Harlap, 1982, 44; Sakr, 1996).

Before the outbreak of the World War I, Lviv architects worked mainly in line with this search for a new Jewish style.

In 1912–1913, the "Jankel Glanzer Schul" Hasidic synagogue at 3 Vuhil'na Street underwent a complete reconstruction. The architect, Włodzimierz Podhorodecki, altered the façades and the space of the prayer room, conforming to the Baroque style modernized in the spirit of Art Nouveau. F. Kassler tried to use the elaborate motifs of old Jewish art from the unrealized project of the Jewish People's House in Lviv (1914).

The pre-burial house "Beth Tahara" ("House of Purification") at the New Jewish Cemetery in Lviv (1911–1913, demolished in 1942) presented a striking ensemble of Jewish Secession. The style of the building constructed by M. Ulam to a design by R. Feliński and J. Grodyński (Budowle wykonane w dziesięcioleciu 1903–1913 przez firmę: Michał Ulam architekt-budowniczy, 1913; Filasiewicz, 1914) combined the trends of Neoclassicism and modernized Romanesque style, with the influence of Secession works by Otto Wagner (e.g. the Church of St. Leopold Kirche am Steinhof), and focus on the old Jewish architecture and ornamentation (Fig. 6).

On the façade, the motifs of Jewish ornamentation were noticeable in the decoration of inter-window half-columns. Inside, the walls of the room approximately 30 m high, covering a space of 600 sq. m, were abundant in frescoes and stained-glass windows by Feliks Wygrzywalski. In these, the artist employed compositional and decorative techniques of Art Nouveau, floral and geometric ornaments, and the re-evaluation of the motifs used in the decoration of synagogues in the 17th and 18th centuries (Jüdische Interessante Blatt, 1913, 1914).

A new house of the Jewish religious commune was erected in 1912–1913 at 27 Blacharska (I. Fedorov) Street to a design by Leopold Reiss and Artur Schleyen. The architects used stylized Renaissance motifs in the arrangement of the main façade. Pilasters with "diamond" rustication, together with the entrance portal and the attic, made the appearance of the new tenement house similar to that of the Jewish architecture of Lviv in the 16th and 17th centuries. Another appeal to the local Renaissance could be seen in the large three-level stepped attic of the Academic House (Jewish Student's House) of the Jakob and Laura Herman Foundation at 7 Królewska (today's Y. Slipyi) Street (architect Adolf Piller, 1910–1911) (State Archives of the Lviv Region, Collection 2, Registry 1, File 5522, pp. 9–18).

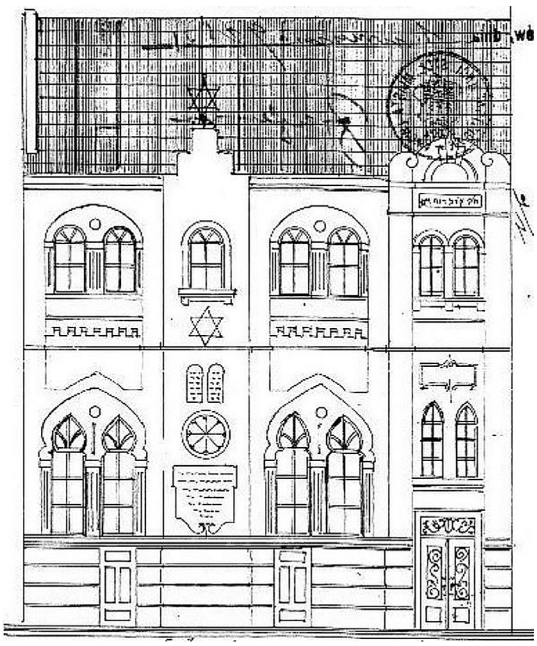

Figure 4. Façade of the "Col Rina ve-Yeshua" ("Shouts of Joy and Salvation") Synagogue. 1905. State Archives of the Lviv Region

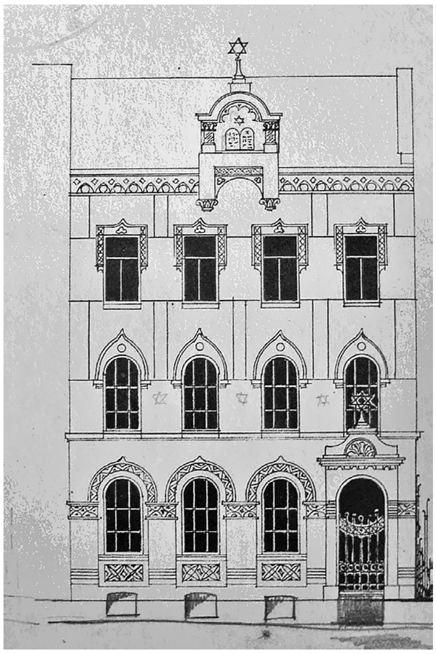

Figure 5. Façade of the synagogue belonging to the "Beth-Lechem" ("Bread House") Society. 1912. State Archives of the Lviv Region

Figure 6. "Beth Tahara" ("House of Purification") pre-burial house at the New Jewish cemetery. 1911–1913. Photo of 1913. Lviv Historical Museum

Figure 7. Tenement house of Isaac Hersz Sandel at 5 Kurbas Street. 1906–1907. Photo: Ilia Levin, 2010

We can also mention other examples of attempts to implement the idea of Jewish national identity in Lviv's residential architecture of the early 20th century.

The tenement house of Isaac Hersz Sandel, built by Salomon Riemer in 1906–1907 at 5 Rejtan (Kurbas) Street, boasts a façade entirely covered with a decorative "carpet" of majolica tiles with an Art Nouveau stylization of Moorish Oriental motifs (manufactured at the workshop run by brothers Jacob and Maurycy Mund) (Fig. 7).

Another (apart from the house at Sienkiewicz Street) building making up the property of Jakub Seinwell Reiss, built in the "Rational" Secession style, to a design by Leopold Reiss at 4 Obertyńska (Zarytski) Street in 1909–1910, was decorated with a unique stained-glass composition on the staircase with traditional Jewish art motifs.

The building of Abraham Kinzler and Jan Marek, referred to as the "House of Winemakers", was erected in 1912–1913 at 49 Pekars'ka Street to a design by architect Walery Szulman in the "Rational" Secession style (State Archives of the Lviv Region, Collection 2, Registry 2, File 2315). The sculptor, presumably Franciszek Tomasz Biernat, referred to the symbols of the Old Testament and Palestine, using them as bas-reliefs depicting a grape harvest—a theme widely used in the visual propaganda by Galician Zionists. The stained-glass windows of the staircase, with images of vines, are similar to the sculptural leitmotif.

The tenement house of Mojżesz Rohatyn at 12 Third of May (Sichovykh Striltsiv) Street, built by R. Feliński in 1912–1913, features a Neo-Romantic mood, with freely "flowing" clear-cut shapes. The façade and interiors acquired details borrowed from Oriental art, in addition to the motifs of the Middle Ages and Renaissance. In particular, the portal half-columns and inter-window columns featured carved Moorish and Jewish designs.

The intensive and brilliant development of Jewish architecture in Lviv came to a halt at the beginning of the World War II and the tragedy of the Holocaust.

Conclusions

The period from 1848 up to 1918 saw the exceptionally intensive interpretation of the patterns of specific regional art and folk art in architecture and related arts. In the second half of the 19th century, the Jewish architecture of Lviv was characterized by the development of transformed Moorish style and other modernized Oriental motifs. At the same time, on that basis, the first attempts were undertaken to shape a unique Jewish artistic style, especially during the Art Nouveau period. The stylistic design strategy of the 1900-1910s was aimed at shaping Jewish cultural identity by creatively applying the principles of traditional Eastern (predominantly Moorish) architecture and the local Renaissance and Mannerist architecture of Galicia, without simply copying their elements and forms. The program acceptance of the new style suggested bringing into play the traditions of the old Jewish art of Eastern Galicia, including the architecture and decoration of synagogues of the 17th–18th centuries. Underlying the phenomenon

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of Lviv's Jewish architecture is the employment of Western European influences, combined with the rich local cultural experience. During and after the World War II, many landmarks of Jewish architecture were irretrievably damaged or destroyed. Nevertheless, Lviv still boasts an enormous number of valuable artifacts that are landmarks of Jewish culture. This legacy requires care, conservation, and a sound scientific description.

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MOHSEN FOROUGHI (1907–1983): THOUGHTS AND SUSTAINABILITY IN THE WORKS OF AN IRANIAN MODERNIST ARCHITECT

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Abstract

Introduction: Mohsen Foroughi was one of the first-generation Iranian modernist architects who joined Iranian architecture in the 1940s. His knowledge of architecture obtained in one of the most important French architectural schools—École des Beaux-Arts—allowed him to create valuable works by combining the spirit of Iranian architecture with modern values. His interest in education led to the establishment of the foundations of architecture teaching in Iran, based on the lessons taught in Europe. **Purpose of the study:** The article addresses the works of Mohsen Foroughi, combining modern architecture with the vernacular Iranian architecture. His most significant works include the building of the Senate, the Department of Law at the University of Tehran, the National Bank of Tehran's Bazaar, and the Saadi Tomb in Shiraz. The article looks at the development of intellectual flows of the time that evolved into social relationships. **Methods**: In the course of the study, we use descriptive analysis and analysis of library resources. **Results**: The main characteristics of Foroughi's work are balance, symmetry, and application of the main elements of traditional Iranian architecture. By better understanding of his works, architects can be more successful in creating today's architectural projects.

Keywords

Mohsen Foroughi, contemporary architecture, Iranian architecture, Saadi Tomb, National Bank, modernism.

Introduction

Mohsen Foroughi was the son of famous statesman Mohammad-Ali Foroughi. He was sent to France to study abroad in 1926, where he chose the École des Beaux-Arts, specializing in architecture. He graduated in 1937, coming first in his class and winning the prize for the best diploma (Gillet, 1983), and came back to Iran in the same year and taught at the various Departments of the University of Tehran, including the Department of Engineering. He was instrumental, along with André Godard, Roland Dubrul, and Maxime Siroux, in establishing the University of Tehran's College of Fine Arts in 1940 and was one of its initial professors, eventually succeeding Godard as its dean (Marefat and Frye, 2000).

Foroughi was the architect of numerous public buildings. He also advised and carried out several restoration and building projects for the National Monuments Council of Iran, including designs for the mausoleums of Saʿdī in Shiraz (Figure 1) and Bābā Ṭāher in Hamadān. Foroughi collaborated with Godard, Siroux, and Dubrul on the design of the master plan for the University of Tehran and its associated buildings, including the Department of Law and Political Science (Marefat, 1988, Marefat and Frye, 2000).

Mohsen Foroughi is one of the most influential architects of public buildings, although the design of several villas is also featured in his repertoire. He is one of the founders of the academic system of architectural education in Iran along with Godard. This architect is considered as one of the most influential people in the Iranian modern architecture movement. Most of Foroughi's architectural works have led to the creation of sustainable architecture, which, of course, should all be included in the heritage of contemporary architecture.

Figure 1. Saadi Tomb, Shiraz, Iran (Ph.: Omid Hatami)

Methods

In line with studying the cultural fundamentals in Foroughi's architectural works, we shall first analyze the physical and structural elements in Iranian architecture by using a descriptive and analytical approach. This method was used before in a similar research by M. Shahidi (Shahidi et al., 2010).

The fundamentals might have changed throughout the history of Iranian architecture; however, in terms of context, they can be used as sets of indicators by architects (Moghaddasi and Zamanifard, 2013).

Research objectives

1. Foroughi's work principles

Mohsen Foroughi was a modernist architect who admired Iranian culture and history. He stated that the formal representation of history in the works of his young colleagues is superficial and believed that the relations between buildings can be divided into two following groups: evident and metaphorical relations. In Foroughi's opinion, an example of the evident relation is the relation between the Sassanid and Achaemenid buildings with Sassanid architecture remodeling Achaemenid architecture (Banimasoud, 2009).

The metaphorical relation is when architects employ the best materials of their time by respecting vernacular architecture.

Foroughi considered climate and materials to be the most important elements. He believed that the major differences in architectural styles are due to the variation of materials and the approach of architects to them. Foroughi also recognized the climate of Iran as one of the most essential factors affecting architectural design (Banimasoud, 2009).

Some of his masterpieces include the colleges of the University of Tehran (1938), the National Bank of Isfahan (1941), the National Bank of Bazaar (1945), the Ministry of Finance, the Agricultural Bank (1953), the building of the Senate (Figure 2), and the House of Iran in Paris (in collaboration with Ghiai, Zafar and others in 1962).

Foroughi had a semi-historical look at the architecture of public buildings before 1951. Therefore, the use of raised columns and turquoise tile in the facades of buildings, the focus on the entrance, and the utilization of concrete or stone can be considered the effects of Foroughi's works on the Iranian architecture of that period.


Figure 2. Senate Building, Tehran, Iran (source: wikipedia.org)

Foroughi's works can be classified into three categories depending on the period and style: national neoclassical style, modern international style, and modern progressive style (Sabatsani, 2014).

The most important point about Foroughi's works is that so far, no comprehensive research has been performed in their regard.

2. Founder of the modern Iranian architecture

Foroughi presented us with the idea of a new architecture and taught us how to use modern technology in architecture. Architecture and technology form and shape ideas, making them visible and tangible. According to Dr. Falamaki, every architectural project belongs to all humankind (Falamaki, 2002).

The authentic Foroughi's architecture overcame all obstacles of the past and was spread by Foroughi himself and others. To critique his works, we must first understand his thoughts. According to Mohammad Reza Haeri: "An architect cannot be defined by a project, and a project cannot only represent an architect. Interpreting the functions of plans and maps is not an architectural critique. We should get acquainted with Foroughi first, and then look at his works." (Bavar, 2002).

2.1. Roots of modernism among Iranian intellectuals

In the face of past architectural traditions and the late industrial revolution in Iran, we can consider the Constitutional Revolution as the turning point in Iranian architecture, after which great changes gradually began to emerge. Although it did not succeed completely, the Constitutional Revolution paved the way for the future, laid new social foundations, and built new relationships. Despite the fact that the effects of this profound transformation and disruption in architecture were not immediate, they moved things forward in an effort to put an end to the dependence on the past political and governmental systems. Politicians familiar with the science and industry came to the forefront, and with passion and enthusiasm, they tried to bring some features of Western industrial civilization to Iran. The very beginning of the transformation was a new way of life, which directly affected Iranian architecture. In the first decade of the new century, with the start of the Pahlavi dynasty, extensive construction began, which obviously cannot be commensurate with that of the past centuries in terms of speed. The actual beginning of architectural developments in Iran coincides with the beginning of the new century (1922 (1300 HS)), especially since at the same time, the country witnessed fundamental political and governmental changes, which were the result of the socio-political transformation. It started with the beginning of the Constitutionalist Movement, with the signing of the constitutional order and the formation of the National Assembly, producing a positive political outcome. The government came to the fore and created a context for the coup of 1921 (1299 HS) (Bavar, 2002).

The changes that took place in Iranian society and the way of life opened the way for transformation in architecture and the spread of cities. With better overseas communication, recognition and the possibility of using technical and structural improvements in architectural activities were provided. Since architecture has always evolved in line with social, political, and economic changes, we need to determine the timing and causes of corresponding changes in architecture.

Those who analyze architecture should have a close look at the thought of the past. The problem that is on our minds today is how our century was formed and how the roots of modern thought were replaced in the hearts of people. To do that, we need to consider the milestones of the past. Returning to the past is not just a matter of examining its events—it needs to be felt and touched so that it can be transformed. The factors that brought about these behavioral, national, and political changes should also be analyzed along with their impact on each other. “One needs to know which of the past events is more important for this age.” (Giedion, 1967).

Mohammad Ali Foroughi and Sayyed Hassan Taqizadeh were representatives of the second generation of Iranian intellectuals, and their political activities, along with their academic and cultural activities, were essentially the result of their nationalist, secular, and modernist ideas. Foroughi knew very well that modernism was based on reason, and that the translation of Descartes’ theory and the emphasis on the phrase “I think therefore I am” were a way to bring the concept of rationality to the depths of Iranian society. Individuals such as Foroughi longing for public progress and the usefulness of nations can be found among Iranian intellectuals and reformists: Taghi Arani, Mohammad Ali Jamalzadeh, Sayyed Hassan Taqizadeh, Morteza Moshfegh Kazemi, Mohammad Asemi, Hossein Kazemzadeh Iranshahr, etc. Publications of Kaveh, Iranshahr, Farhangestan, scientific and artistic works on such topics as public education, women’s rights, war against prejudice, translations of European books, and the adoption of particular principles and conventions show that the European civilization is reforming Iran. The first issue of *Nameh-ye Farhangestan* (*Academy’s Letter)* states: “What do we want? We want Iran to awaken from its centuries-long hibernation”. According to many scholars of that period, this awakening was due to tolerance to the Western civilization through the complete acquisition of the foreign civilization conditional on the preservation of the Persian language. That tolerance resulted in a set of writings and translations, the most famous of which are the translation of Descartes’ work, the natural philosophy of Ibn Sina, *The Course of Wisdom in Europe* by Mohammad Ali Foroughi, translations of Kafka by Hedayat, translations of Chekhov by Bozorg Alavi, the short story *Persian is Sugar* written by Mohammad Ali Jamalzadeh, *The Horrible Tehran* by Morteza Moshfegh Kazemi, and the play *Ja’far Khan Returns From Abroad* by Hassan Moghaddam, represent the encounter of Iranian second-generation intellectuals with modernity (Jahanbegloo, 2001).

In the Iranian society, both the contemporary intellectuals and the interim government wanted Iran to move towards global progress, face the advanced world with its technical, artistic. and constructive innovations. All the modern and advanced Iranians wanted Iran to wake up from a silent, motionless sleep. The Iranians, who were moving forward, sought for rationalism, development in such areas as science, technology, and agriculture. They aimed to bring modern technology, resource management, as well as waterways, airways, and motorways, to Iran. They also wanted to get along with other advanced countries. Intellectuals were essential and helpful for both the government and society.

Iran was a backward country: it was lagging behind everything in all fields. Therefore, seeking to escape backwardness, the uninhibited society needed a new path to the future.

The set of issues that Iran faced in the late Qajar period was the result of years of sluggish agriculture affecting family livelihood. However, the result of this backwardness in Iran has not yet been determined definitively.

“For this reason, Iranians as a product of the Iranian civilization with its views and values, are neither completely traditional nor absolutely modern. They look both to the modern world and the world of traditions.” (Jahanbegloo, 2001).

In the first and second decades of the new century, with the coming of the new regime, construction started in various fields (construction of roads and other basic facilities, government buildings, schools, radio and telecommunication systems, railways, bridges, airports, industrial plants, etc.)—the country urgently needed to develop industry, economics, and construction, and engage in global politics. The era was very active and dynamic. A series of tensions and trends remaining from the past continued to pave the way for the future. There is no doubt that our culture is based on the legacy of the past generations, and the systematic process of socio-political and economic changes maintains. Trying to move quicker, our society was bound to create new starting points and pursue another path (Giedion, 1967).

This was how Mohsen Foroughi took the path of the political and cultural regime of the time. It was the road to modernization and modernity, the way

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to confront the advances of the modern world in art, architecture, and technology.

Why did not Foroughi use Sasanian architecture or motifs and architectural forms of Achaemenid art in his works like Godard?

Neither Foroughi, nor the other architects such as Abkaar, Vartaan, and Gurkian went back to the architecture of the past. Instead, they tried to move forward and create works that would not only introduce spatial innovations and new building techniques but also confront the architectural advances of the Western world. Foroughi did not use traditions as a model in his modern architecture since the modern movement had occupied his conscience and thought. This meant a complete awareness of the beginning of a new era, which Foroughi was trying to present by creating new architectural spaces. Foroughi deliberately stepped in and laid the foundations of modern architecture in Iran.

As mentioned earlier, modern thought became common in Iran before the Constitutional Revolution. Before the Constitutional Revolution, Abbas Mirza tried to modernize the Iranian Army. Amir Kabir and Sepahsalar made efforts to familiarize Iranians with new science and education programs. With the start of the new era, activities aimed at the modernization of Iran were carried out in two ways. On the one hand, Iranian students were sent to Europe to study science and gain knowledge, and on the other hand, European engineers and experts were brought to Iran to set up schools and educational centers run by the government. “The reformists of that period did not believe that the general public, or traditional scholars and systems, could implement their ideas. For example, Seyyed Jamal al-Din Assadabadi thought that reliance on religious power had not led to any civilized progress in Iran. However, such progress could be achieved through the recognition of the technological advancements of the West.” (Jahanbegloo, 2001). Thus, with the coming of the Pahlavi government, the country’s political life changed considerably. In the first decade of 1300 HS, groups of young people were sent abroad to study. Among them, Foroughi, Vartaan, and Abkaar can be mentioned.

After returning, they were engaged in intellectual activities. So, who was Foroughi and what role he played in the emergence of modern architecture in Iran?

Foroughi, a son of Mohammad Ali Foroughi (Zak’’a al-Molk), grew up in a political and cultural family. Between 1929 and 1935, he completed his university studies in architecture at the School of Fine Arts in Paris (École des Beaux-Arts) and then returned to Iran. At the time, the country was expanding, modernizing virtually all social, cultural, structural, and industrial aspects. So, there were plenty of opportunities to advance expertise.

In post-Qajar Iran, government planners sought to find technological solutions, implementing a gradual shift in construction to specific activities and innovations regarding education, intelligence, and social culture. They knew that modern educational and specialized institutions had originated from the development of cultures, higher education, and research. In general, it led to cultural changes that can be the only correct response when dealing with the slow process and the same technology of the past in architecture and civil engineering.

It seems that the basic principles of the Iranian modernization plan accounting for educational and cultural advancements can shape all construction activities. Besides, with account for the quality of space, construction activities open up in terms of environmental creativity and social reality, by eliminating various forms of imposed life style. Educational advancements can help solve problems and, contrary to what is available, they are a robust and predictable force that in the first two decades of 1300 HS, the spirit of times in the field of culture and education, had quite a positive effect considered the essential and necessary means in the development of society (Wilber, 2003). It was also believed that the primary focus of the new organization of education should be not a service for all but its further development in relation to the transformation, as a social framework of perceptual and conceptual presence.

The government, the intellectuals, and those responsible knew that modern educational and specialized institutions could form the entire required structure. With regard to the advancements in technology and construction, it will help overcome social backwardness and move forward confidently, facilitating the expansion of all manufacturing sectors, as a result of the progress of social civilization.

Figure 3. National Bank of Bazaar (exterior view), Tehran, Iran (Photo By: Saeb Kefayati)

2.2. Emergence of a modernist architect

Under these conditions, Foroughi appears on the scene.

With the political backing inherited from Zaka al-Molk (his father) and due to his father's prominence in political and cultural activities of the Iranian political community, Foroughi found himself in a pre-fabricated atmosphere and quickly entered the field of cultural and political action.

Foroughi's activities can be divided into two categories: activities in the field of politics; activities in the field of engineering.

As for politics, after returning to Iran, Foroughi was elected as a representative in the National Assembly. Later he became a Senate representative.

His career in engineering developed in three directions: cultural; archaeological and artistic; architectural.

Foroughi was the second and the most important director of the College of Fine Arts in the University of Tehran after Andre Godard, the founder and chairman of the College. He had a distinct, calm, and solemn character. He talked slowly and treated students with respect, thus, he was much respected himself. His colleagues included Sadeq Hedayat, the Director of the College library and translator of training programs from the École des Beaux-Arts of Paris, Mr. Ghahrampanpur, the College Secretary, Mr. Moghadam who taught art history, and Eng. Sanei, Eng. Sayhoun, Eng. Farman Farmaeian, and Eng. Ghiai.

As for architecture, Foroughi's works can be viewed as the systematic architecture of the first Pahlavi period. His buildings are more than objects in a national neoclassical style and, while large-scale and bulky, they are distinguished by a particular elegance. Foroughi did not return to any forms of the Iranian architecture of the past but tried to use more advanced techniques of the West and make them perfect in his buildings. He believed that there was "a massive revolution in politics and thought, which produced outstanding works that could be a strong and justified reason for revolutionary events in architecture" (Collins, 1998).

He was trying to create a new contemporary architectural thought that other architects attempted to achieve at the same time in Iran and the West.

Some of his most valuable works employing the most advanced technologies of that time include the Department of Law, University of Tehran (1938) (Zarkesh, 2012), the National Bank of Isfahan (1941), the National Bank of Tehran's Great Bazaar (1944) (Figures 3, 4), and the Agricultural Bank (1953) (currently the Trading Bank of Fayyaz Bakhsh, North Side of Park City). It should be noted that employers of that time were educated, enlightened and civilized people. Among his activities, we can mention participation in the design and implementation of the Senate building in cooperation with Heydar Ghiai and Kayqhobad Zafar. Foroughi believed that "the characteristic feature of modernism is a permanent change, and progress is an essential human action suited to human needs".

Let us take a look at the Isfahan National Bank (Figures 5, 6). "At the corner, from the west side to the south, this rectangular volume of cubes ends with a semi-circular veranda. This veranda provides light to the architectural space, leading the eye to the other side. From the bottom to the top, there are narrow and long columns. They enter into a conflict with the main body, making a huge and heavy volume with a very elegant style." (Bavar, 2001).

Other works of Foroughi include the Dorud railway station, the residential building of Mr. Ghahraman Bakhtiar (northern corner of the Rumi Bridge), his residential home on Pahlavi street, the residential building of Mr. Lak on the Yakhchal street opposite the Qavam House, which has become a park today, the Ministry of Finance, the Saadi Tomb (in collaboration with Ali Sadegh), the Tomb of Reza Shah (in collaboration with Ali Sadegh and Kayqhobad Zafar) (Adle and Hourcade, 1992).

The other joint work of Foroughi and Ghiai is the Maison de l'Iran Building in Paris (1968) (Figure 7).

This project was developed in a general office in Tehran by Claude Parent, André Bloc, Moshen Foroughi, and Heydar Ghiai, Eng. Iraj Ghiai and Eng. Kamran Sepahbodi who contributed to the

Figure 4. National Bank of Bazaar (interior view), Tehran, Iran (Photo By: Bank Melli Iran's website (National Bank of Iran))

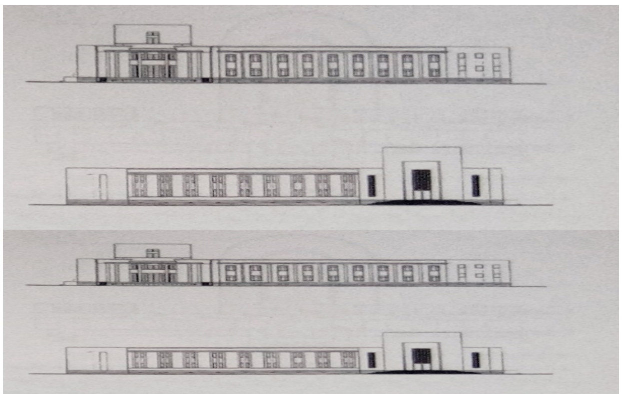

Figure 5. National Bank (architectural sections), Isfahan, Iran (Drawing By: Cyrus Bavar)

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preparation of the plans. The building consists of three metal frameworks with a height of 38 meters, and two lightweight four-story blocks suspended over several meters. The metal stairs interlocking in the block are designed by André Bloc, whose expertise in sculpture made the building prominent.

Results and discussion

Foroughi was very interested in archeology and had a thorough knowledge of antique items. He had a valuable collection of antiques at his home, specializing in ancient coins and seals, and visiting scholars were always welcomed and assisted in studying his collections. He was a senior adviser to André Godard and Roman Grishman and an expert in visual arts, especially impressionism.

In addition to being fluent in French, Foroughi was familiar with some of the Iranian ancient languages. He had a scientific, artistic, and political personality, and embodied outstanding moral qualities. He was a very humble, good-natured, humorous, communicative, and curious person, aware of the global issues and continuing Iranian traditions. Foroughi resigned from the College of Fine Arts in 1962 due to political conflicts, but his atelier remained there in his name.

Looking at Foroughi's works, we can see that he had special skills in combining the principles of Western modernism with traditional Iranian architecture using two general ways. For instance, in the Senate building, which was directly inspired by the works of the Achaemenid and Sassanid periods, we can find the main architectural elements of that time, such as the Pillar Hall, which is an evident relation. In another group of his works, a metaphorical relation can be observed: Foroughi used the best materials and techniques of the time while respecting the common principles of Iranian architecture, such as privacy, context-based materials, and climate-friendly design. Context-based materials were clearly used in all his works both in Iran and France.

The academic principles that Foroughi established in architectural education in Iran can be seen to this day. Before him, architecture was traditionally taught orally, based on the teacher-student relationship in architecture workshops. After the establishment of the College of Fine Arts, traditional knowledge was combined with new methods of teaching and transformed into a modern form. Foroughi was well aware of the onslaught of contemporary modernism at the time and, using his knowledge and patriotism, prevented damage to the original Iranian architecture. In fact, he transformed modernity in Iranian architecture and defeated modernism in Iran like the previous invasive cultures in Iran (the Arab and the Mongol invasions). While his works represent contemporary Iranian architecture, they also express his spirits and personality traits. The importance of Foroughi's work is so vital that contemporary Iranian architecture can be divided into two categories: before and after him, since his role in educating the architects of the next generation is quite clear.

Foroughi taught us how to think and how to form and shape our age, whether through the creation of modern society or the creation of contemporary spaces. His dignity and balance are seen in all his architectural works: the Department of Law at the University of Tehran, the National Bank of Bazaar, the National Bank of Isfahan.

Figure 6. National Bank (entrance view), Isfahan, Iran (source: deskgram.net)

Figure 7. Maison de l'Iran, Paris, France (Hidden Architecture website: http://hiddenarchitecture.net)

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ARCHITECTURE OF RUSSIAN EXHIBITION PAVILIONS AT INTERNATIONAL NORDIC EXHIBITIONS IN THE LATE 19TH – EARLY 20TH CENTURIES

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Abstract
Introduction: In the 19th – early 20th centuries, Russia actively participated in world's and international exhibitions in Europe and the USA. **Purpose of the study:** We aim to study the typology of Russian expo construction abroad consisting of three branches: construction of model facilities, construction of official ceremonial buildings and facades, and, finally, construction of exposition pavilions. **Methods:** Despite the inevitable demolition of the facilities, Russian exposition pavilions built abroad always strained after high quality of architecture, which is quite important. **Results:** A peculiar type of buildings — the Russian national exhibition pavilion — formed, which is traditionally styled after old Russian architecture but, at the same time, meets the new exposition and functional requirements.

Keywords
World's and international exhibitions, architecture of Russian national exhibition pavilions, Russian style of the second half of the 19th century.

Introduction

World and international expos were the brightest manifestations of social life in Europe in the second half of the 19th – early 20th centuries. Russia took an active part in these exhibitions starting with the first 1851 world's fair in London. It was there where foreigners learned about Russian industrial, agricultural, and artisan items, visual arts, and architecture. Participation in these fairs not only helped Russia to strengthen its trade ties with the West and accelerate its engagement in the global capitalist system but also brought to life a completely new type of buildings — the Russian national exhibition pavilion.

A feature of the world's and international expos of the 19th century was that the countries that organized these fairs built huge expo buildings (general and themed) where the exhibitions of all the participating states were demonstrated. This preconditioned the nature of the artistic finish of Russian sections in the form of national facades or decorations inside the expo buildings. These structures played primarily an advertising role and were particularly styled. The Russian style was represented by a folkloric line of development of Russian wooden architecture in the second half of the 19th century (Nikitin, 2014a).

The organizers of the Paris World's Fair in 1878 made a provision that the participating states should build pavilions in their national style that would become sort of a street of nations at the Champ de Mars. These facade pavilions acted as grand entrances to the galleries of a huge expo palace with the expositions of the participating countries.

The Russian pavilion was the centerpiece of all structures built on the street of nations. It was a two-story wooden structure (40 x 5 m) consisting of towers and turrets decorated with multiple carvings of bright colors and combined with a gallery. Probably, the wooden palace in the Kolomenskoye village was the prototype of this structure. Even foreign researchers noted the stylistic closeness of these buildings (Lamarre and Leger, 1878).

Russian structures at the World's Fairs of 1867 in Paris and 1873 in Vienna also attracted the attention of the public and the critics, but the real triumph of Russian architecture was in 1878. The author of the building, Ivan Ropet (the real name — Ivan Petrov), already known due to the Moscow Polytechnic Exhibition of 1872, became very popular in Paris and made a sensation. His structure prompted a great response both in the foreign and national press.

The stylistic characteristics of Russian structures at the 1878 World's Fair in Paris were associated with a strong architectural movement existing in Russia in the second half of the 19th century and taking its cue from the old Russian architecture. Representatives of this movement — students and followers of Professor A. M. Gornostayev — in trying to give their structures not only national but also folk character were inspired by specimens of peasant architecture and applied arts. They understood the task of giving architecture the folk character as the task of decorating their structures with details borrowed from folk art, and not only from wooden architecture but also from folk embroidery. This style, in contrast to the official "Russian style" of K. Thon, was supported by the democratic public. In this regard, *Motifs of Russian architecture* lithographic albums published in the mid-1870s by A. Rheinbott are quite interesting. These albums included designs by Bogomolov, Walberg, Hartmann, Gun, Kuzmin, Monighetti, Ropet, Kharlamov, etc. (Rheinbott; 1874–1880). This was a sort of manifest of Russian national architecture that revealed the artistic motto of representatives of this architecture movement.

I. Ropet had a complicated task: to create a distinguished image of the Russian national pavilion, original grand propylaea leading to the Russian exposition at the World's Fair. It was not an exhibition pavilion in the truest sense of the word because it included not only the exposition but also the administration of the Russian section headed by the Commissioner-General, Mr. G. Butovsky. At the same time, the "facade" was also a showpiece. It was an advertising, "representational" structure that laid the foundation for a whole range of architectural patterns stylized after the old Russian architecture. This special purpose of the Russian exhibition pavilion, in some way, preconditioned the entertaining and advertising nature of its architecture (Nikitin, 2007). It should be noted that public opinion on the capability of the Russian national style to "decently represent Russia and 'Russian character' abroad" was already shaped by the late 1870s (Lisovsky, 2000).

Russia had to prove to the West that it had a style, authentic and self-sufficing. That goal was reached. Ropet's "facade" that became somewhat of a trademark of Russia at the fair, the dazzling success of the artistic section made the West talk about the Russian national school of art (Imperial Academy of Arts, 1879; Matushinsky, 1879). According to A. M. Matushinsky, a reporter from the Golos newspaper, "for the first time, Europe saw first hand the Russian art developing authentically and independently" (Borisova and Kazhdan, 1971, Kondratov, 2006).

The assessment of the exhibition structures of I. Ropet by experts of that time varied: from the enthusiastic review of V. V. Stasov to derogatory names such as "ropetovshshina", "cockish style", "highly refined mishmash", etc. In the history of Russian architecture, the Paris "facade" made by I. Ropet became a classic example of no sense of proportion in decorations and irrationalism, and for some researchers — an example of the "pseudo-Russian style" (B. M., 1909). Was it the Russian style? Was the Ropet's creative work an example of national art for his fellow men? This question was raised many times, and no unambiguous answer was found. The author of the obituary published in the *Zodchiy* journal after Ropet's death answered this question in the following manner: "This is, of course, an open question: it was something new, original, with a peculiar taste — something quite understandable by the masses. This was 'ropetovshchina', and it took its place in the history of Russian architecture" (Russian State Historical Archive, Fund 20, List 1). Such an assessment of Ropet's creative work by his fellow man is interesting because for the first time it raised the question of architecture as a popular art.

Subject, tasks, and methods

The Russian facade at the 1878 Paris World's Fair laid the foundation for a whole range of architectural patterns, stylized after the old Russian architecture,

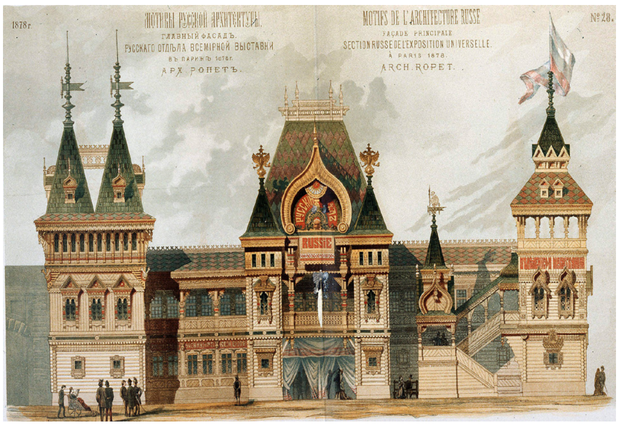

Figure 1. Main facade of the Russian section at the Paris World's Fair of 1879. Design. Architect: I. Ropet. Motifs of Russian architecture. 1878. No. 28

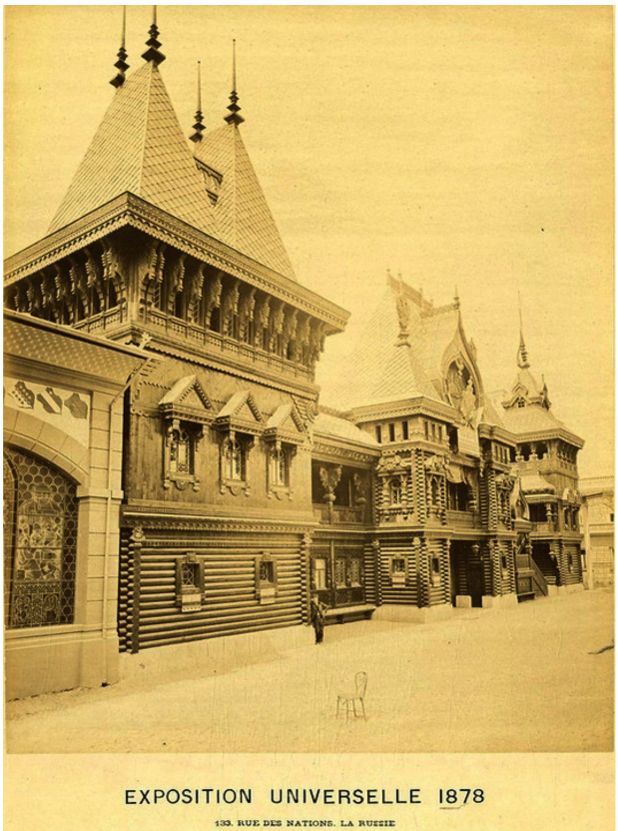

Figure 2. Entrance pavilion of the Russian section at the Paris World's Fair of 1878. Architect: I. Ropet. Rare photo. 1878

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that did not perform the expo functions. This special purpose of the Russian exhibition pavilion, in some way, preconditioned the entertaining and advertising nature of its architecture. A similar technique of decorating the entrance to the Russian section was used at the World's Fairs pf 1888 in Copenhagen and 1897 in Stockholm. It is interesting that I. Ropet earned high distinction in France and Denmark and was awarded the Legion of Honor and the Knight's Cross of the Order of the Dannebrog (Russian State Historical Archive, Fund 40, List 1).

The exhibition of industry, agriculture, and art was held in the very center of Copenhagen — in Tivoli Gardens — in 1888. The Russian section was in the grand main pavilion between the French and British sections. The wooden entrance pavilion of Russia was built by a design of I. Ropet and resembled a gatehouse church highly decorated with carving.

It is interesting that, sometimes, Russia resorted to the help of foreign designers and developers during the arrangement of its sections at foreign expos. For instance, at the 1867 Paris World's Fair, the Russian stabling was built by the French: "at the instructions of the Commission, French architects Benard and Cambreling made designs and estimates on site" (Hoppe, 1889). Russia did not participate in the 1889 Paris World's Fair officially since the exhibition was timed to the 100th anniversary of the French Revolution of 1789. However, some items from Russia participated in the exhibition, and Russian architecture was represented by the French. At Quai d'Orsay, architect J.-L.-C. Garnier made a retrospective exhibition of human housing where

Figure 3.Entrance pavilion of the Russian section at the international exhibition of industry, agriculture, and art of 1888 in Copenhagen. Architect: I. Ropet

one of the structures was mimicking a Russian boyar house (Grin, 1897). This construction practice was also used at the expos in Sweden.

From May till September 1897, the General Art and Industrial Exposition of Stockholm was held, which was called Nordic. It was held in association with the 25th anniversary of the reign of King Oscar II. The fairgrounds were located on Djurgården Island occupying an area of 21 ha near the Skansen, the oldest open-air ethnographic museum. Ferdinand Boberg was the chief architect of the expo. The main themed pavilions were made according to his designs. The largest pavilion was the Palace of Industry that included the expositions of Sweden, Norway, and Denmark. A large dome with a crown-like open-work structure at the top was a structural accent of the building. Four minarets were adjacent to the dome. Their tops were connected to the top of the dome with bridges. An observation deck was also made, which could be accessed by elevators. The main pavilion made of wood was a peculiar high-rise centerpiece of the expo with a height of almost 100 m. The erection of such a large wooden building was a very complicated task, and, according to the reporter, it was "a trick that set experts in engineering wondering" (Report of the Commissioner-General at the Art and Industrial Exposition of Stockholm of 1897).

The Russian section was located in a low semi-circle annex to the grandiose Palace of Industry. It had a framed structural layout, a sloping conic glass roofing, and occupied 1540 sq. m. Presumably, the building was built to the design of Swedish architect F. Boberg. He also participated in making the interior decoration of the Russian section (Report of the Commissioner-General at the Art and Industrial Exposition of Stockholm of 1897).

The architecture of the pavilion built by the Swedes received criticisms from the organizers of the Russian section. "The interior had a low glass roof looking like a curve and many thin quadrilateral columns supporting the roof. They completed the appearance of this inconspicuous building. The pavilion of the Russian section made a hard impression as compared to the adjacent section of industry (where the Danish, and then the Swedish and Norwegian pavilions were located), which was full of light, air, had a beautiful outlook, and was very tall", P. Miller, the Commissioner-General of the Russian department, wrote (Report of the Commissioner-General at the Art and Industrial Exposition of Stockholm of 1897).

To remedy this situation and give the Russian section a smart appearance, it was decided to add an entrance pavilion to the existing building. The design of the entrance pavilion was made according to the sketches of St. Petersburg artist B. Nikolayev and approved by the Minister of Finance, S. Witte, on 17 February 1897, i.e. as recently as three months

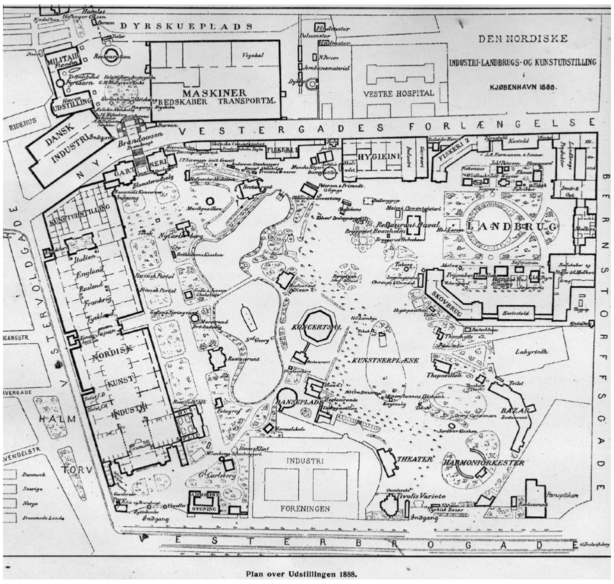

Figure 4.Exhibition of industry, agriculture, and art of 1888 in Copenhagen. General layout

Figure 5. Exhibition of industry, agriculture, and art of 1888 in Copenhagen. General view of the exhibition area and the entrance pavilion of the Russian section

before the opening of the exposition (Report of the Commissioner-General at the Art and Industrial Exposition of Stockholm of 1897). The entrance pavilion was built by S. A. Olsson, a Swedish firm. It cost 6000 krones, which corresponded to as little as 3130 rubles.

The entrance pavilion was made in the spirit of wooden church structures of the Russian North of the 17th century. A large keeled bochka roof of the entrance portal was cut into a high tent-shaped roof whose crown had an inscription "Russia" in the spirit of the handwritten ornamental design of the 14th century. The structure was also influenced by the Nordic wooden architecture. This was manifested in the details of the windows, balustrade, and decorations of the roof ridges.

The Russian section was very popular among the visitors of the fair. It demonstrated the high quality of Russian national products. In total, 305 Russian exhibit items were shown at the expo; 149 of them received awards, 43 of them received gold medals, 57 — silver medals, 35 — bronze medals; 14 exhibit items received honorable mentions, and 9 companies were given the title of "the suppliers of the Kings of Sweden and Norway" (Russian State Historical Archive, Fund 387, List 15).

More than 2,000,000 people visited the Nordic Fair. About 20,000 of them were from Russia. Many members of the Imperial family and the Minister of Agriculture and State Property, A. S. Yermolov, also visited the fair.

The Russian section at the Baltic Exhibition in Malmö was built by the Russian Chamber of Commerce. It used the "business" principle as opposed to the usual, so to say, "representational" principle. The organizers of the section, representing the state and commercial interests of the exhibitors, tried to show that Russia could act as an exporting country at the Nordic market. This was the "state and public task to be fulfilled by the Russian section at the Baltic Exhibition" (Ahlström,

Figure 6. General Art and Industrial Exposition of Stockholm of 1897. Panorama sketch of the exposition

Figure 7. General Art and Industrial Exposition of Stockholm of 1897. Industrial pavilion. Architect: F. Boberg

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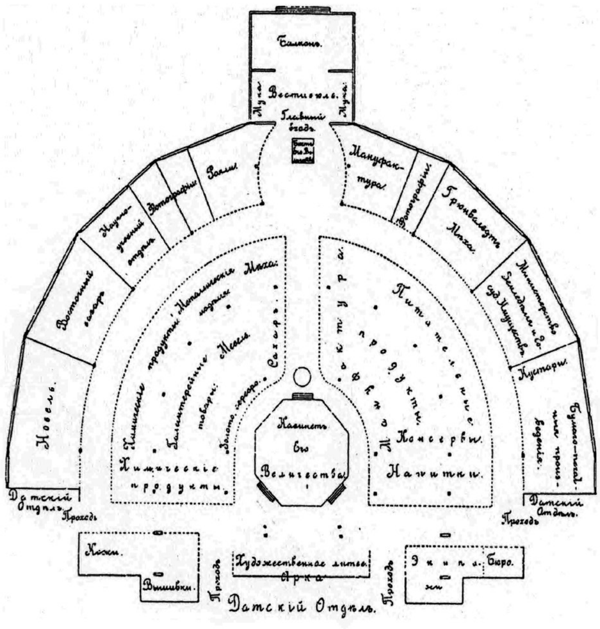
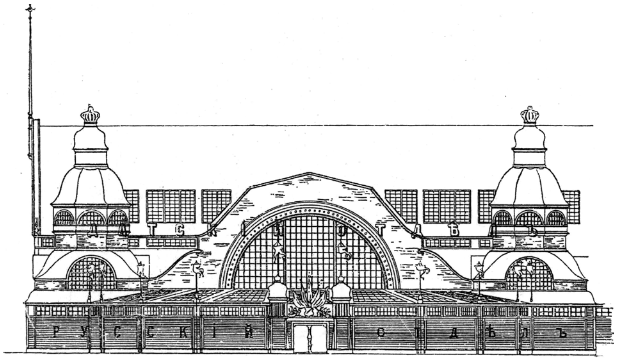


Figure 8. General Art and Industrial Exposition of Stockholm of 1897. Layout of the Russian section.



Русскій Отдѣлъ до постройки входнаго павильона.

Figure 9. General Art and Industrial Exposition of Stockholm of 1897. Facade of the Russian section before the entrance pavilion was built.

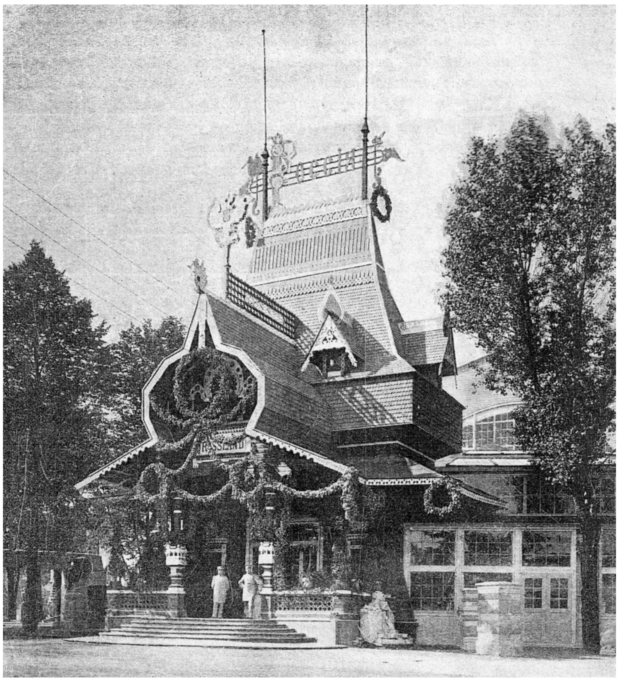


Figure 10. General Art and Industrial Exposition of Stockholm of 1897. Entrance pavilion of the Russian section. Artist: B. A. Nikolayev

Figure 11.Baltic Exhibition in Malmö in 1914. Poster of the exhibition

1915–1919). The Russian participants were provided benefits for the transportation of exhibit items and fee-free permits to return to Russia.

The exhibition was held under the auspice of Swedish King Gustav V and was honorably chaired by Crown Prince Gustaf Adolf from 15 May till 4 October 1914. It was held in a large territory of 49 ha in the picturesque Pildammsparken. Exhibit items of four countries — Sweden, Denmark, Germany, and Russia — were demonstrated at the exhibition. The Finnish exposition was part of the Russian section. All member states built their national pavilions. Sweden had the largest exposition that was placed in several themed pavilions. Various musical and sports events were held at the time of the exhibition. More than 800,000 people visited the expo.

Figure 12.Baltic Exhibition in Malmö in 1914. Facade of the Russian pavilion. First sketch.
Architect: F. Boberg

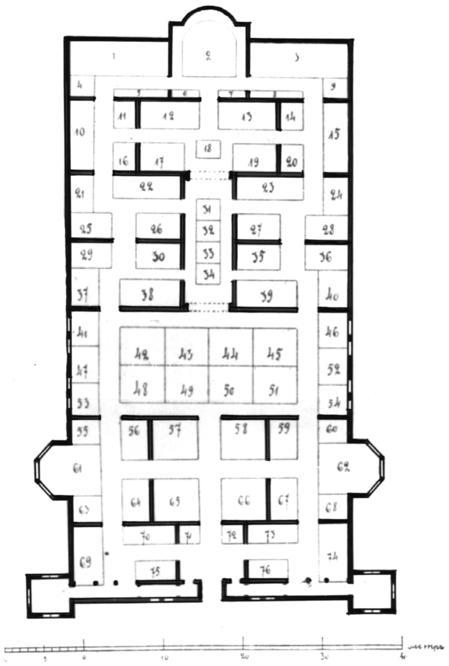


Figure 13. Baltic Exhibition in Malmö in 1914.
Russian pavilion. Layout

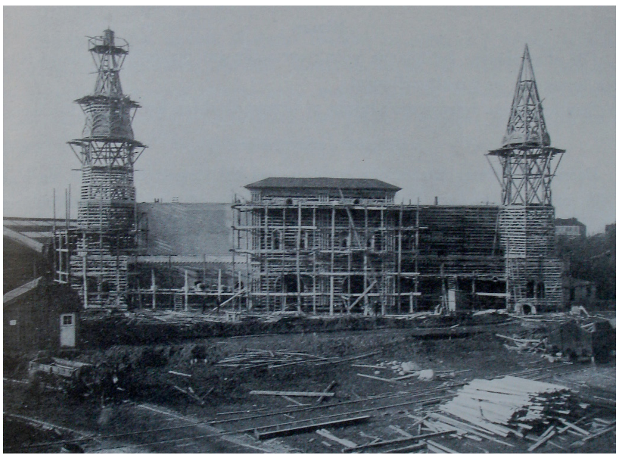


Figure 14. Baltic Exhibition in Malmö in 1914.
Russian pavilion. View of the construction activities

The Russian pavilion followed the old Russian style and was built using a traditional showcase design. It represented a wooden frame with plastered external walls. It occupied the area of 2300 sq. m. Two tent-shaped bell towers of a traditional design (octagon placed on quadrangle) towered at the corners of the main facade of the slightly gloomy building with almost lacking side windows. A clear symmetrical layout was based on a combination of small and large transversal halls connected functionally into a single suite. The unique pass-through layout and overhead lights indicate a rather mature type of exhibition building. It should be noted that administrative premises of the Russian section and a Russian restaurant were also placed in the pavilion.

For a long time, the authorship of this unique building was unclear. Recently, this information has been found in the Malmö City Archive. The Russian pavilion was built according to the design of Chief Architect Ferdinand Boberg who also participated in the erection of the Russian section at the Stockholm expo of 1897. However, these data require clarification since, as it happens, a renowned St. Petersburg architect, M. Peretyatkovich, participated in designing the pavilion.

An agreement was reached between the Russian Chamber of Commerce and the administration of the Baltic Exhibition in Malmö. Under the agreement conditions, the designer of the expo, F. Boberg, prepared the design of the Russian pavilion during the summer of 1913 (Ahlström, 1915–1919). When F. Boberg presented his design to the Committee of the Chamber of Commerce, he reported that the design was not final and that he would be happy if a Russian architect could look through it and express his opinion. The Chamber of Commerce presented the design to M. Petetyatkovich who, after carefully studying it, made some changes to give the building a historical appearance and then delivered it back to the Chamber of Commerce. The design edited by M. Peretyatkovich was accepted by the steering committee of the Baltic Exhibition (Nikitin, 2014b).

After the start of the erection works, a new difficulty arose. It threatened, while not making the construction impossible, to significantly delay it. In the Vecherneye Vremya newspaper for December 1913 and, later, in a number of Swedish newspapers, an article was published where Russian architect Kravchenko sharply criticized the appearance of the Russian pavilion and judged that the design was by a Swedish architect, rather than a Russian one. A scandal arose. Architect F. Boberg whose sketches were the basis for the Russian pavilion design was deeply wounded by these sharp accusations since his sketches were processed by Russian architect M. Peretyatkovich through the Russian Chamber of Commerce. F. Boberg was

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Figure 15. Baltic Exhibition in Malmö in 1914.
Russian pavilion. Interior of one of the halls

Figure 16. Baltic Exhibition in Malmö in 1914.
Russian pavilion. Photo of 1914

going to refuse to participate in the construction of the pavilion and suggested that the steering committee of the Baltic Exhibition should choose a Russian architect who would undertake the finishing design of the Russian pavilion in order to transfer this obligation to the Russian party. After intense correspondence between the organizers of the exhibition and the Russian Chamber of Commerce, the scandal ended. The construction works continued, and the Russian pavilion was absolutely complete both on the inside and the outside by the opening day.

World War I led to the early closing of the Russian and German sections, urgent export of the Russian exhibit items, and the departure of the participants back home. However, the collection of the Russian artistic section consisting of 56 pieces of pictorial and graphical art remained in Sweden. Russian art was represented by such renowned artists as A. N. Benois, I. Ya. Bilibin, A. M. Vasnetsov, V. V. Vereshchagin, A. Ya. Golovin, K. A. Korovin, B. M. Kustodiev, I. I. Levitan, V. Ye, Makovsky, K. S. Petrov-Vodkin, V. D. Polenov, M. S. Saryan, Z. Ye. Serebryakova, V. A. Serov, V. I. Surikov, I. I. Shishkin, and others (25 artists in total). This unique collection of Russian art is still at the museum of fine arts in Malmö. It is interesting that Malmö grandly celebrated the 100th anniversary of the Baltic Exhibition in 2014. Scientific conferences, themed exhibitions, and advertising events were organized. In October 2014, an exhibition of Russian art (opened for the general public at the Russian section at the Baltic Fair of 1914) from the funds of the Malmö museum of arts was held.

Results and discussion

Russian exhibition structures, having original artistic solutions, each time were one of the most remarkable national structures. On the one hand, they reflected the main trends in the development of architecture in Russia and, on the other hand, they resulted from the certain points of view of the organizers of the world's fairs on the architecture of a new type, the national exhibition pavilion. The specifics of the architecture of these buildings required obligatory stylization, return to the authentic forms of the past, which made it possible to give to the public the ultimate expression of a national style and distinguish the buildings from the pavilions of other participating countries. A prominent national tinge of Russian exhibition structures was not an exception. It was in line with the general architectural practice of the countries that participated in world's fairs (Lukomsky, 1911).

Conclusions

Starting with the first structures at the Paris World's Fair of 1867, Russia brought the old Russian architecture to all the subsequent expos. The Russian pavilions at the fairs of 1911 in Rome and Turin, built using designs of architect V. A. Shchuko and stylized as the Russian classical architecture, were a rare exception from this rule (Lukomsky, 1911).

The practice of Russian expo construction abroad consisted of three branches: construction of model facilities, construction of official ceremonial buildings and facades, and, finally, construction of exposition pavilions. A peculiar type of buildings — the Russian national exhibition pavilion — formed, which is traditionally styled after old Russian architecture but, at the same time, meets the new exposition and functional requirements. Despite the inevitable demolition of the facilities, Russian exposition pavilions built abroad always strained after high quality of architecture, which is quite important. Russian architects tried to create an original image of the Russian national exhibition pavilion. That is why using old Russian architecture was understandable. The Russian path at world's and international expos was not accidental. It was a path of affirmation of the Russian national culture in the West.

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АРХИТЕКТУРА ВЫСТАВОЧНЫХ ПАВИЛЬОНОВ РОССИИ НА МЕЖДУНАРОДНЫХ ВЫСТАВКАХ В СКАНДИНАВИИ В КОНЦЕ XIX—НАЧАЛЕ XX ВЕКА (РОССИЯ)

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Аннотация

Россия активно участвовала во всемирных и международных выставках в Европе и Америке в XIX — начале XX века. **Цель исследования:** Изучение типологии выставочного строительства России за рубежом, которое осуществлялось в трех основных направлениях: сооружение образцовых построек; официальных, «представительских» зданий или фасадов; и, наконец, экспозиционных павильонов. **Методы:** Важнейшей особенностью выставочного строительства России за рубежом было постоянное стремление к высокому качеству архитектуры, несмотря на неминуемый снос этих сооружений. **Результаты:** Сформировался специфический тип здания — национальный выставочный павильон России, традиционно выдержанный в формах древне-русского зодчества, но при этом отвечающий новым экспозиционным и функциональным требованиям.

Ключевые слова

Всемирные и международные выставки, архитектура национальных выставочных павильонов России, русский стиль второй половины XIX века.

Civil Engineering

GENERATING A PROBABILISTIC CONSTRUCTION SCHEDULE

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Abstract
Introduction: The design stage and preparations for construction include the development of construction schedules needed to justify the duration of construction works. **Methods:** Based on probabilistic scheduling, a multitude of solutions can be generated for each implementation roadmap (progress chart). These decisions can be defined as optimistic, most probable or likely, and pessimistic. Rational roadmaps are selected in accordance with benchmarking. Simple and discounted payback periods are used as frequently applied criteria included in the system of evaluating the economic effectiveness of investment projects. Based on identifying the given indicators of project evaluation, a method of designing probabilistic construction progress charts has been developed; the latter serve as the basis for devising respective organizational-technological solutions. **Results:** The design of optimistic, pessimistic, and most probable construction roadmaps (schedules or progress charts) enables the use of a developed model for probabilistic prognostication of future production risks affecting the delay of construction completion.

Keywords
Construction scheduling, project management, organizational-technological reliability, probabilistic network construction models, delayed construction.

Introduction

At the stage of design and preparations for construction, carried out as part of the construction organization project, a roadmap or calendar progress chart is developed to justify the duration of project construction and the duration of its various stages (Government of the Russian Federation, 2008). The following recommendation aimed at the selection of organizational-technological solutions is given in Regulations 48.13330.2011 (Ministry of Regional Development of the Russian Federation, 2011): "Construction organization decisions should be based on studying alternatives and using benchmarking and modeling methods as well as modern hardware and software." Following the given recommendation, one can assume that studying calendar progress chart alternatives must be based on a modern project management system that includes statistical modeling methods and the *PERT* method (PMI, 2008) leaning on optimistic and pessimistic assessments of work durations. A respective benchmark evaluation of alternative construction roadmaps (calendar progress charts) is to be determined by relevant valuation parameters for assessing the economic effectiveness of investment projects (Ministry of Economy of the Russian Federation, Ministry of Finance of the Russian Federation, State Committee for Construction, Architecture and Housing Policy, 2000).

When probabilistic scheduling methods are used, developers of calendar progress charts bear in mind that the construction process is liable to accidental exposures while respective durations of works should be expressed as random variables. The first study (Gusakov et al.,1977) highlighting general matters of probabilistic scheduling gives recommendations on developing and using probabilistic network models in construction. Yet there are no specific recommendations for the numerical definition of all probabilistic characteristics peculiar to calendar progress charts. One of the later works (Barkalov et al., 2010) points out that almost all systems of probabilistic scheduling assume that the density of distribution regarding work duration time estimates is to have three properties: continuity, unimodality, and two nonnegative points of its intersection with the x-axis. The authors further argue that it is a beta distribution that meets these criteria, whereas probabilistic parameters are set by three alternative durations of works: optimistic, pessimistic, and the most likely ones. As regards the quantitative determination of these parameters, Barkalov et al. suggest that these are to be provided by managers in charge of construction works, or based on available norms and standards or on actual experience. It should be noted straight off that the analysis of modern databases regarding labor norms shows the lack of probabilistic norms or standards (Bolotin and Kotosvksya, 2013, Porshneva, 2011; Solin, 2011).

The recommendation to use the expert evaluation method is relevant, as proven by Velichkin (2014): "The deadlines can be assumed on the basis of experience and available expertise…." Anferov et al. (2013) say: "The lack of any ways to take into account the probabilistic nature of the construction process that includes construction and power-driven (mechanized) works lowers the reliability of organizational-technological and managerial decisions in the industry." A similar handicap exists in project management software: there is a module meant for the *PERT* method to be used in the *Microsoft Project* software, but the input of probabilistic parameters is methodologically undefined (Kupershtein, 2011).

In some works, you can come across certain criticism of the *PERT* method and even find some recommendations on how it could be improved; however, this criticism and recommendations suggested have nothing to do with the quantitative definition of probabilistic durations of works (Oleynikova, 2008, 2013). There is no easing of this bottleneck in the international PMBOK standard geared towards the use of the project management system (PMI, 2008).

Thus, the main purpose of the given article is addressing the practically relevant task of justifying the values of temporal characteristics of the probabilistic construction roadmap developed within the construction organization project.

Materials and Methods

Prior to the beginning of design and project-oriented preparations for the construction process, a technical assignment for the design of a capital construction project is set. The standard form of the technical assignment was developed and approved in 2018 by the Russian Ministry of Construction, Housing and Utilities. Among other things, the given form contains information about the presence or absence of a project investor, which can be used to develop and assess the pessimistic and optimistic alternatives of the calendar progress chart (construction roadmap). The hypothesis embraced by the authors of this article was chosen because the alternative related to capital attraction requires additional expenditures disbursed at the discounting rate *E* describing the dependency of the money cost on time (Copeland et al., 1995). In the alternative defined by the lack of attracted capital, there are no extra expenditures. The alternatives presented spawn divergent assessments of the project payback period.

The most graphic illustration of this discrepancy is equations used to find the discounted payback period *DPB* and simple payback period (*PB*). The simple payback period can be calculated using the following equation:

$$\int_0^T c(t)dt = \int_T^{PB} r(t)dt \quad , \qquad (1)$$

where *c(t)* is the differential distribution of capital investments in time;
r(t) is the distribution of the recurrent cash flow in time,
T is the construction duration.

The discounted payback period is calculated using the following equation:

$$\int_0^T \frac{c(t)}{(1+E)^t}dt = \int_T^{PB} \frac{r(t)}{(1+E)^t}dt \quad . \qquad (2)$$

Both the above-mentioned equations describe the consecutive fulfillment of investing and operating periods defined by cash flows related to project construction and management of a built facility. For the assumed sequence of investing and operating periods in the project's life cycle, the ratio of the discounted to simple payback periods will always be more than 1.

$$ID = \frac{DPB}{PB} > 1 \quad . \qquad (3)$$

The given inequation shows that investment funds attracted increase the payback period and this delay depends above all on the adopted discounting rate. The hypothesis of our choice lends itself to the following rationale. Since almost any investment construction project is estimated both in terms of the simple payback period and the one with a discounted cash flow, the ratio of the discounted to simple payback periods may serve as a yardstick of untimely execution of future construction works.

Let us focus on the proposed model of calculating probabilistic durations of works using the example of a simple calendar process chart for the construction of a residential building, comprising the following cycles of consecutive works: preparatory and underground works, aboveground works and interior fit-out works. The choice of the given scope of works coincides with the structure of works used in construction duration standards (Repository for legal documents, standards, regulations and specifications, 2020). For the method described below, the value of the standard presented comes down to information about the distribution of capital investments by months of construction activity. The given standards coupled with consolidated standards of construction costs (Repository for legal documents, standards, regulations and specifications, 2014) allow a complete reproduction of the investment cash flow *c(t),* even without a detailed feasibility study. This being said, minimum information about a future facility is needed in case of residential buildings: wall structure, floor count, and total area.

The recurrent cash flow *r(t)* related to a built facility depends either on the sale schedule and the price per unit of space or on the rental price of built premises. If this information is missing, then it is necessary to set the discounted payback period *DPB* and discounting rate *E* in order to figure such annuity of presumed income that would match the preset payback period. The following equation can be used for the calculations:

$$\sum_{i=1}^{T} \frac{c_i}{\left(1+E\right)^i} = A\left(1+E\right)^{T/12} \frac{1-\left(1+E\right)^{T/12-DPB}}{E}, \quad (4)$$

where C_i is the distribution of investments by months until the construction completion *T*, also expressed in months; *A* stands for the annuity.

The left part of equation (4) represents cumulative investments discounted by the construction start date and calculated with due regard for investments to be provided towards the end of the month (Kovalev, 1998). The right part of equation (4) represents the value of discounted annuity whose duration is determined by the difference between the discounted payback period expressed in years and construction duration expressed in months (Repository for legal documents, standards, regulations and specifications, 2020). Equation (4) can be used to arrive at the equation of calculating the annuity that would ensure the discounted payback period, given the preset discounting rate:

$$A = \frac{E\left(1+E\right)^{T/12}}{1-\left(1+E\right)^{T/12-DPB}} \sum_{i=1}^{T} \frac{c_i}{\left(1+E\right)^i}. \quad (5)$$

With reference to the known annuity, one can find the simple payback period using equation (6):

$$PB = T/12 + \frac{\sum_{i=1}^{T} c_i}{\sum_{i=1}^{T} \frac{c_i}{\left(1+E\right)^i}} \frac{1-\left(1+E\right)^{T/12-DPB}}{E\left(1+E\right)^{T/12}}. \quad (6)$$

It should be borne in mind that the distribution of capital investments in time can be expressed both in absolute and relative parameters represented in Construction Rules and Regulations SNiP 1.04.03-85 (Repository for legal documents, standards, regulations and specifications, 2020). As per the earlier determined payback periods, one can then calculate their ratio and assume it to be the ceiling value of the index of delayed works *ID*. Under this estimation of the maximum relative delay of construction works in the calendar process chart, a definite positive factor is that it is in full harmony with the criteria of estimating the effectiveness of investment construction projects.

Discussion

Bolotin et al. (2014) review the method of space-time analogy showing an increase of relative works' execution delay in case of the absolute construction start date incrementing. Based on this method, a model of calculating the pessimistic work execution time is proposed that includes the planning horizon *H* found by means of equation (7):

$$H = \frac{3}{\ln\left(1+E\right)}. \quad (7)$$

Bolotin and Dadar (2016) consider a similar calculation model; yet a different equation is suggested for the planning horizon (8):

$$H = \frac{\pi}{2\ln\left(1+E\right)}. \quad (8)$$

The numerical value of the planning horizon calculated by means of equation (7) is almost twice as high as the value obtained by means of equation (8), while it does not seem possible to rationalize which of the values is more correct. Therefore, the construction project's payback periods are used as an analog of the planning horizon in the model laid out in the given article.

The calculation of pessimistic durations, proposed by Bolotin et al. (2014), Hejducki et al. (2015) is done using equation (9):

$$t^{pes} = \frac{H \cdot D}{H - L - S + D/2}, \quad (9)$$

where *D* is the work's determined duration; *L* is the duration of works on a project; *S* is the determined (fixed) beginning of works.

Equation (9) shows the increasingly pessimistic duration of the work as it approaches the planning horizon. Equation (9) includes the duration of project works, which is rather uncertain. The circumstances mentioned above decrease the value of the given model. This is why Bolotin and Dadar (2016) propose an alternative equation based on the link between the pessimistic duration of the work and the discounting rate.

$$t^{pes} = \frac{\left(1+E\right)^{S+D} - \left(1+E\right)^S}{\ln\left(1+E\right)}. \quad (10)$$

As a result, the calculation of the pessimistic duration of the work lacks uncertain values, but at the same time, the given equation does not take into account an important characteristic of the project, such as the distribution of capital investments in time, even though the latter, as was demonstrated above, affects the project's payback period. Bolotin and Dadar (2016) point out that in the process of deriving equation (9) it was neglected that new pessimistic durations generate a new timetable and new start dates; as a result, the given calculation is correct only for the first iteration.

The model based on using payback periods, proposed in the given article, addresses the above-stated issues in the following way. We

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bring the maximum delay index into conformity with the discounted payback period and assume that the most likely value of the current delay index will be proportionate to time *t* from the construction start date to the construction end date.

$$ID^{mid} = 1 + \frac{ID}{DPB} \cdot t. \quad (11)$$

The pessimistic value of the current delay index should be found using equation (11):

$$ID^{pes} = 1 + \frac{ID}{PB} \cdot t. \quad (12)$$

As was suggested by Bolotin and Birjukov (2013), determined (fixed) values of works' durations can be used for the optimistic roadmap. To devise the likely or pessimistic calendar process charts, it is necessary to calculate respective durations of works (e.g. pessimistic t^{pes}). A respective calculation equation can be obtained through integration of the following expression:

$$t^{pes} = \int_{S}^{S+D} (1+\alpha t)dt = D\left(1 + \alpha S + \frac{\alpha}{2} D\right), \quad (13)$$

where α for the pessimistic scenario is the function of the *ID/PB* ratio, while the average value is determined by the *ID/DPB* ratio.

It should be noted that the new value of the work duration is determined as the average duration between the start date and the end date. The start date can be assumed to be fixed, the end date will shift depending on the new value and, therefore, equation (13) should be considered approximate. For a more precise calculation of pessimistic durations of construction activities, Bolotin et al. (2016) propose an iteration procedure related to cyclic readjustment of the timetable. However, experimental data show that the relative addition pertaining to subsequent iterations proved to be less by two orders of magnitude and did not exceed 1%. For the correct calculation of the probabilistic durations, the critical path method should be modernized. The modernization applied boils down to the fact that in the calculation of end dates one should figure probabilistic durations using equation (13) instead of their determined (fixed) values.

Results

Let us show the practical result using the example of generating a calendar process chart (roadmap) containing the schedule of integrated territory development with three residential buildings. The parameters of these buildings are taken from the construction duration standards (Repository for legal documents, standards, regulations and specifications, 2020) and are shown in Table 1. The last column of Table 1 shows the results of calculating the coefficient α included in equation (13) and computed under the following values:

Table 1. Characteristics of buildings in the cluster under development

No.	Type of building	Floors	Area, sqm	Works				Integral distribution of capital investments by months												α
				Under	Prep	Above	Int.	1	2	3	4	5	6	7	8	9	10	11	12	
1	Cast-in-situ	5	1500	1	1	3	1	8	20	40	63	86	100							0.174
2	Cast-in-situ	5	6000	1	1	5	1	5	27	38	49	56	74	95	100					0.164
3	Cast-in-situ	9	12,000	1	1	8.5	1.5	4	9	17	24	35	46	55	64	73	82	92	100	0.139

E = 20% per annum and *DPB* = 5 years. Based on these data, an optimistic timetable of works using determined (fixed) durations of works (see Table 1) is presented in the upper part of Table 2. A pessimistic timetable of works generated using the above-stated methodology is shown in the lower part of Table 2. Each element of both timetables contains the start and end dates, whereas the durations of works matching them are shown below.

The performance indicators of construction, widespread in Russia, include the general duration of construction works, which under the optimistic project delivery scenario comes to 20 months and under the pessimistic scenario — to 22.4 months. The pragmatic result of the calculation presented is that the pessimistic delay of 2.4 months can be duly hedged against and also used to calculate the penalty imposed by a developer upon a general contractor for the supposed untimely commissioning of a cluster under development.

Conclusions

The method of generating calendar construction process charts allows probabilistic organizational-technological design at the stage of design with reliance on information known at the given stage and directly related to the standard system of estimating the economic effectiveness of investment construction projects.

Table 2. Optimistic and pessimistic schedules of integrated development

Buildings		Preparations			Foundations			Aboveground			Interior works		
Optimistic	№1	0		1	1		2	2		5	5		6
			1			1			3			1	
	№2	1		2	2		3	5		10	10		11
			1			1			5			1	
	№3	2		3	3		4	10		18.5	18.5		20
			1			1			8.5			1.5	
Pessimistic	№1	0		1.01	1.01		2.01	2.01		5.08	5.08		6.09
			1.01			1.01			3.07			1.01	
	№2	1.01		2.03	2.03		3.06	5.08		10.6	10.6		11.8
			1.02			1.03			5.52			1.15	
	№3	2.03		3.32	3.32		4.36	10.6		20.6	20.6		22.4
			1.29			1.04			9.96			1.87	

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ФОРМИРОВАНИЕ ВЕРОЯТНОСТНОГО КАЛЕНДАРНОГО ПЛАНА СТРОИТЕЛЬСТВА

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Аннотация
Проектная подготовка строительства включает разработку календарных планов, которые необходимы для обоснования продолжительности строительства. **Методы:** На основе вероятностного календарного планирования для каждого календарного плана может быть сформировано множество решений, определяемые как оптимистичные, наиболее вероятные и пессимистичные. Выбор рациональных вариантов календарных планов осуществляется в соответствии с критериальной оценкой. В качестве часто применяемых критериев, входящих в систему оценки экономической эффективности инвестиционных проектов, используются простой и дисконтированный периоды окупаемости. На основе определения данных показателей оценки проекта разработан метод расчета вероятностных календарных планов строительства, в соответствие с которыми на этапе проектирования строительства объектов формируются соответствующие организационно-технологические решения. **Результаты:** Проектирование оптимистического, пессимистического и наиболее вероятного календарных планов строительства позволяет использовать разработанную модель для вероятностного предсказания будущих производственных рисков, влияющих на задержку окончания строительства.

Ключевые слова
Календарное планирование строительства, управление проектами, организационно-технологическая надежность, вероятностные сетевые модели строительства, задержка продолжительности строительства.

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STRESS-STRAIN STATE OF CURVED LAMINATED WOODEN ELEMENTS DURING PRODUCTION

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Abstract

Introduction: The stress-strain state (SSS) of curved laminated wooden elements may differ significantly from the SSS of straight laminated wooden elements, not only in terms of the curvature but also in terms of production specifics and operational load. A curved element is produced by bending wooden planks (lamellae) and gluing them together. In the process, the structure is subjected to initial internal stresses, as the lamellae tend to straighten out again. After production is complete, the element experiences unequal initial internal stresses, which alters its strength properties in different directions in relation to the timber fibers. At a later point, this is going to contribute to the stresses that the structure experiences under external pressure. The Russian and foreign regulations (SP, EuroCode 5, DIN) do not pay sufficient attention to this fact, which has merited this study. **Methods:** For the aforementioned purpose, we review a mathematical model of the SSS emergence in curved laminated wooden elements. We roughly divide the process into two stages: stage 1 involves bending separate lamellae, gluing them together, and pressing them down; stage 2 involves pressing out the laminated package. This results in prestress, which is a combination of tangential, radial, and shear stresses. **Results:** Our study results in a visual representation of the total prestress during stages 1 and 2. Such a representation allows for predicting stresses in curved laminated wooden structures under alternating operational loads. **Discussion:** We highlight the impact of the relaxation of initial stresses, which requires further study. Depending on the direction and amount of operational load, the curved laminated section of a structure may “attempt” to straighten out (i.e. with a decrease in curvature), or may curve even further. This is not properly reflected in the guidelines for wooden structures’ design and needs to be examined further.

Keywords

Curved laminated wooden element, production of curved wooden structures, initial prestress, combination of initial prestress and operational stresses.

Introduction

The stress-strain state (SSS) of straight laminated wooden structures (LWS) differs from that of curved LWS: the reason is that the latter experience internal stresses during production, as the laminated curves attempt to straighten out. After production, these stresses generate a complex initial stress state, complemented by the stress state caused by external loads, which occur during operation and may vary both in terms of the amount and the direction in which the different sections of the curved laminated structure are affected.

There have been a number of studies on the subject (Gordon, 1973; Serov et al., 2011), but they have been applied, both in theory and experimental practice, exclusively to the cornice joints of hockey-stick type frames, which are invariably subjected to tension along the timber fibers within the outer radius and to compression along the timber fibers within the inner (smaller) radius. The studies do not look at radial compression, as it never results in destruction and always has significant reserves. The results of these studies are still applied to the Russian guidelines on wooden structures’ design (SP 64.13330.2017).

However, it should be noted that when the curved sections of a curved laminated structure bear a load that causes compression with a bend, they start experiencing a “straightening effect”. Under such conditions, even the smallest curvature of the laminated section may significantly affect the stress, which is not considered by the wooden structures’ design guidelines. A straightening force always results in tensile radial stresses across the timber fibers. Our own research (Schmidt, 1980) provides experimental proof that, when thus compressed, an element with a large curvature gets destroyed under the impact of tensile radial stresses. However, we did not conduct any further studies on the subject. Nonetheless, the above applies not just to bent elements (such as curved laminated beams) but specifically to compressed bent elements (depressed pointed arches, frames, etc.) that may experience a straightening force. In summary, the prestress generated during the production of curved laminated wooden structures must be inspected in more detail.

Methods

For convenience, we shall divide the process of curved laminated structures' production into two stages: stage 1, when each of the lamellae gets coated in glue and bent along the required angle, and all lamellae are subsequently pressed together; and stage 2, when the glue dries and the structure relaxes.

The effort applied to bending each specific lamella in the package during stage 1 converts into elastic deformation energy that affects the entire curved laminated package at stage 2. As a result, the stress state of the finished curved laminated element equals the sum of the elastic processes that affect it during the first and second stages. The respective prestress has two mutually perpendicular directions: the radial (along the radius and across the timber fibers) and tangential (at a tangent to the arcs and along the bent timber fibers). With this in mind, we can write down the following generalized equation for the radial (σ_r^{init}), tangential (σ_θ^{init}), and shear ($\tau_{\theta r}^{init}$) prestress:

$$\begin{Bmatrix} \sigma_r^{init} = \sigma_r^{(1)} + \sigma_r^{(2)} \\ \sigma_\theta^{init} = \sigma_\theta^{(1)} + \sigma_\theta^{(2)} \\ \tau_{\theta r}^{init} = ... + \tau_{\theta\rho}^{(2)} \end{Bmatrix} . \quad (1)$$

Here, σ_r and σ_θ stand for normal stresses, $\tau_{\theta r}$ stands for shear stresses, and (1) and (2) superscripts stand for the production stages.

We should note that during stage 1, there are no shear stresses either in separate layers or between them, while the radial $\sigma_r^{(1)}$ and tangential $\sigma_\theta^{(1)}$ stresses are mutually perpendicular in relation to the lamellae axis curves. Importantly, radial stresses at stage 1 are always compressive.

Let us now have a more in-depth look at the stress at stage 1.

Let us assume that each lamella bends strictly along the circular arc with a radius of ρ_i. A circular deformation of this kind can occur when the layer is experiencing pure bending. Therefore, we can conclude that:

$$\frac{1}{\rho_i} = \frac{M_i}{E_i \cdot J_i} , \quad (2)$$

where ρ_i is the mean curvature radius, while M_i, J_i, and E_i are the bending moment, the second area moment, and the modulus of elasticity in layer i, respectively.

We must point out that, if the beam axis has a circular outline, equation (2) shall remain true even for larger bending radii. In this case, calculations require a non-linear dependency between the strain parameters and the displacement components; integrating precise equations will yield a circle equation for the deformed beam axis (Filin, 1978), or for curves with a small radius.

When experiencing pure bending, no layers have shear stresses. There are radial $\sigma_r^{(1)}$ and tangential $\sigma_\theta^{(1)}$ stresses, however; these types of stress end up being principal stresses (axisymmetric problem).

Let us assume that a package consists of identical layers, i.e. $\delta_i = \delta$, $E_i = E$ and $J_i = J$. Then, for layer i, we find the data described in Figure 1.

$$M_i = \frac{E \cdot J}{\rho_i} , \quad \sigma_{\theta i}^{(1)} = \frac{M_i \cdot y}{J} = \frac{E \cdot y}{\rho_i} .$$

Having accepted that $y = \frac{\delta}{2}$ and specified $\beta_i = \frac{\rho_i}{\delta}$, we can find the values of the boundary tangential (or normal to the section) stresses along the edge of layer i during the first stage:

$$\sigma_{\theta i}^{(1)} = \frac{E}{2\beta_i} . \quad (3)$$

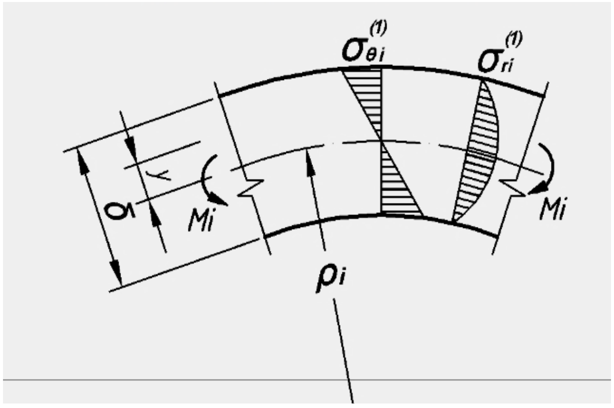

Figure 1. On finding the normal (tangential) and radial stresses in the i^{th} curved layer

Our next step is to find the value of the maximum radial compressive stresses in layer i at the first stage $\sigma_{ri}^{(1)}$, based on the layer's equilibrium equation (Figs. 1 and 2).

$$2\int_F \sigma_{\theta i}^{(1)} dF \cdot \sin(d\gamma) = 2b \cdot \sin(d\gamma) \frac{E}{\rho_i} \int_\alpha^{\delta/2} y \cdot dy =$$

$$= \sigma_{ri}^{(1)} b \cdot r_i \cdot 2d\gamma .$$

As the $d\gamma$ value is fairly small, we shall adopt the following ratio: $\frac{\sin(d\gamma)}{d\gamma} \quad 1$.

Then $$\sigma_{ri}^{(1)} = \frac{E}{\rho_i \cdot r_i \cdot b} \cdot b \int_\alpha^{\delta/2} y \cdot dy .$$

It is obvious that $b\int_\alpha^{\delta/2} y \cdot dy = S^{trunc}$ is the static moment of the section's truncated segment.

For a slightly curved beam ($\beta > 20$), like layer i ($\beta_i \geq 200$) (Schmidt, 1980), it is feasible to assume that the point of maximum radial stresses is the central point within the wood (y = 0). Then $S^{trunc} = \frac{b \cdot \delta^2}{8}$. Bearing in mind that when y = 0,

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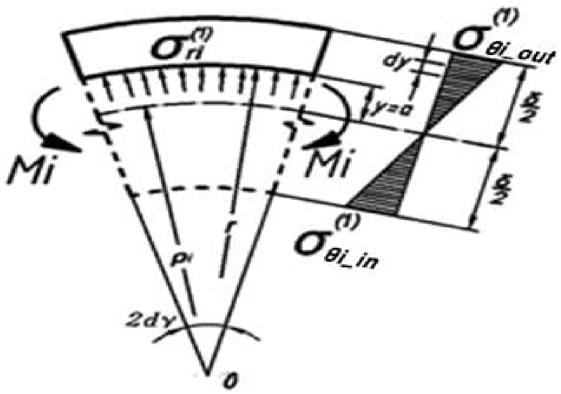

Figure 2. On determining the radial stresses in the I_{th} layer

$r_i = \rho_i$ and $\beta_i = \frac{\rho_i}{\delta}$, we can derive the final values of the radial compressive stresses across the timber fibers:

$$\max \sigma_{ri}^{(1)} = \frac{E}{8 \cdot \beta_i^2} \ . \tag{4}$$

For simplicity, we shall hereinafter refer to as max $\sigma_{ri}^{(1)}$ as $\sigma_{ri}^{(1)}$.

The straight layers, which get curved before the gluing process, shift in relation to one another within the boundaries of the curved section's central angle, by Δl_i (Fig. 3). Notably, this shift decreases from the bottom layer Δl_1 towards the topmost layer Δl_n, since it only affects the curved section and is in reverse proportion to the curvature radius.

While in this state, the layers are pressed together; the impact of the press (after pressing-out) has almost no effect on the SSS of the curved laminated layers' package.

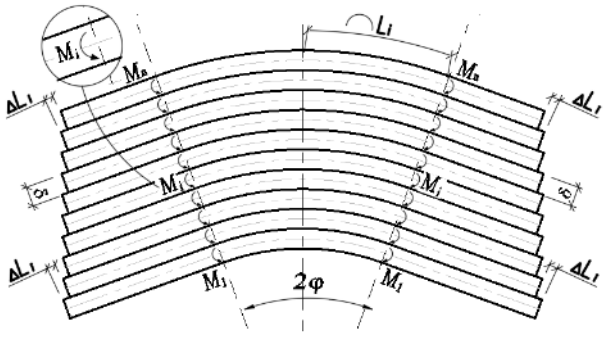

Figure 3. Deformed state at production stage 1

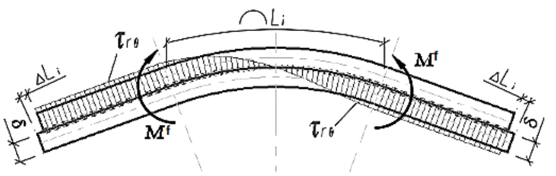

Figure 4. Distribution of shear stresses in the glue seams during stage 2 (package pressing-out)

We shall now move on to the stress at stage 2, when the glue dries and the curved laminated element is pressed out. The package pressing-out process takes approximately 24 hours to complete. During this period, the glue gains around 80% of its strength and undergoes little deformation, preventing the lamellae from splitting and shifting in relation to one another, despite the force that compels the layers to straighten out.

Aside from the stresses that were generated at stage 1 ($\sigma_{\theta i}^{(1)}$ and $\sigma_{ri}^{(1)}$), those lamellae layers that undergo "pure bending" also begin to experience shear stresses $\tau_{\theta r}^{(2)}$ at stage 2. The stresses occur in the seams between the layers and prevent them from shifting and straightening out (Fig. 4).

We shall determine the shear stresses (Fig. 4) by examining the relative shear strains in the seams, which equal the ratio between Δli and the length of the corresponding curved section of each lamella li. Then the shifts in relation to the initial layer, which used to be straight before the bending, will equal $\varepsilon_i = \frac{\Delta l_i}{l_i}$. Beyond the curved section, we shall define the maximum values of the shear stresses in glue seams as follows:

$$\tau_{\theta ri} = G \cdot \varepsilon_i . \tag{6}$$

where G is the shear modulus of the hardened glue seam, which is usually taken equal to the shear modulus of the timber along the fibers.

Therefore, now that we have established that the physical and mechanical properties of the glue seam are similar to those of timber, we can assume that, once the glue hardens, this will result in a single and solid anisotropic body with a uniform structure, experiencing a complex stress-strain state (in essence, a prestress state).

The internal energy of the curved beam layers that are deformed by bending feeds the compulsion to undo the bend. We shall replace the cumulative action of all the bending moments M_i that affected each layer previously with a static equivalent . In this case, pressing out the package is going to equal subjecting a curved beam, glued together from curved wooden lamellae, to a certain fictitious bending moment M^f, which equals M but has the opposite direction (Fig. 5):

$$M^f = \sum_{i=1}^{n} M_i = \sum_{i=1}^{n} \frac{EJ_0}{\rho_i} = E \frac{b \cdot \delta^2}{12} \ln(1 + \frac{n}{\beta_1}) \ , \tag{7}$$

where b is the width of the plank package, n is the number of planks (lamellae) in the package.

It is evident that, when subjected to M^f , the curved laminated element attempts to unbend (straighten out). In order to properly define the resulting stresses, we can use a dependency for assessing the properties of an anisotropic beam with a large curvature under pure bending conditions

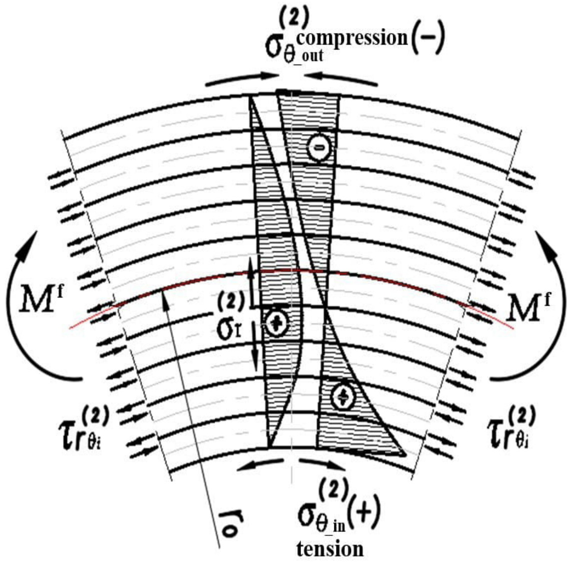

Figure 5. Stress state of the curved laminated beam during stage 2 (pressing out the glued package)

(Lekhnitsky, 1977; Schmidt, 1980). Specifically, we can use the known pure bending equations (American Wood Council, 2015; Foschi, 1971) for the boundary tangential stresses along the inner edge $\sigma^{(2)}_{\theta\_in}$ and along the outer edge $\sigma^{(2)}_{\theta\_out}$, as well as for the maximum radial stresses $\sigma^{(2)}_r$:

$$\sigma^{(2)}_{\theta\_in} = \frac{M^f}{W}\left(1+\frac{1}{2\beta}\right), \quad \sigma^{(2)}_{\theta\_out} = \frac{M^f}{W}\left(1-\frac{1}{6\beta}\right),$$

$$\sigma^{(2)}_r = \frac{M^f}{W}\frac{1}{4\beta}, \qquad \tau^{(2)}_{\theta r} = G\cdot\varepsilon_i, \qquad (8)$$

where $\beta = \frac{r_{av}}{h} = \frac{\beta_1}{n} + \frac{(n-1)}{2n}$ is the relative curvature radius for the entire element.

We must stress that in this instance, unlike in Regulations SP 64.13330.2017 (Ministry of Construction, Housing and Utilities of the Russian Federation, 2017), it would be preferable to use alternative terms for the curved beam edges: “inner vs outer” rather than “upper vs lower”, as in some modern structures, the curved sections can be positioned with their inner (concave) part at the top and outer (convex) part at the bottom. In other words, the inner edge is the edge closest to the center.

By substituting (3), (4), (5), (6) and (7) in equation (1), we find the initial prestress experienced by a curved laminated wooden element, specifically the prestress for boundary tangential stresses, shear stresses along the glue seam, and maximum radial stresses in each layer:

$$\begin{cases} \sigma_r^{init} = -\dfrac{E}{8\beta_i^2} + \dfrac{M^f}{W}\dfrac{1}{4\beta} \\ \sigma_{\theta\_in}^{init} = -\dfrac{E}{2\beta_1} + \dfrac{M^f}{W}\left(1+\dfrac{1}{2\beta}\right) \Rightarrow \\ \tau_{\theta r}^{init} = G\cdot\varepsilon_i \end{cases}$$

$$\left.\Rightarrow \sigma_{\theta\_out}^{init} = \frac{E}{2\beta_1} - \frac{M^f}{W}\left(1-\frac{1}{6\beta}\right)\right\} . \qquad (9)$$

Figure 6 illustrates the general process of hypothetical graphic cumulation of the curved element’s stress during both stages, given that the number of layers (lamellae) n = 10. Here, the stress diagrams for stage 1 and stage 2 are comparable in scale to the extent of the stresses, which affirms the existence of the resulting compression (-) along the inner edge fibers, tension (+) along the outer edge fibers, and tension (+) across the fibers at the center throughout the section height.

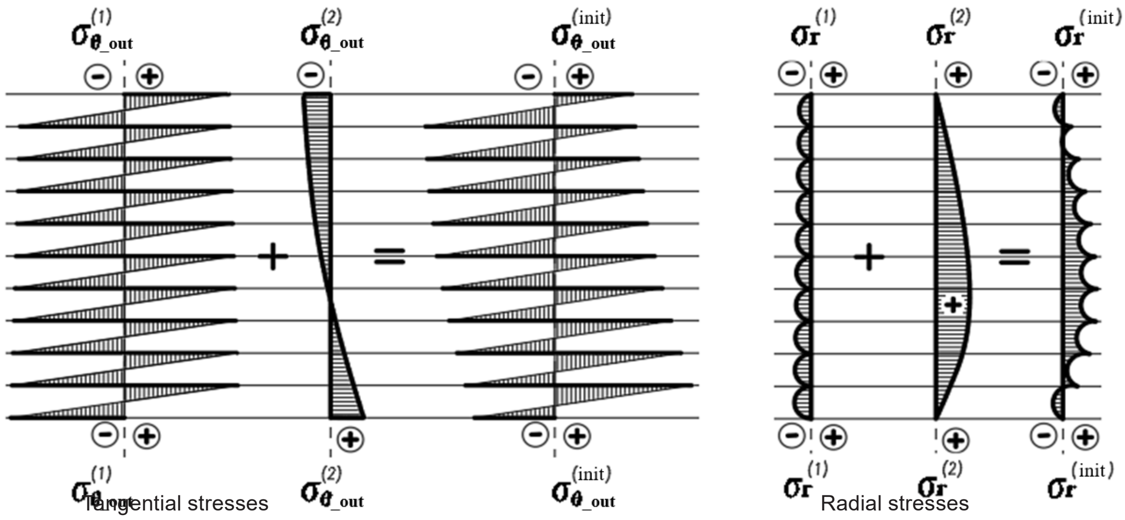

Figure 6. Cumulation of tangential and radial stresses at stages 1 and 2 of curved laminated beam production

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In summary, a curved laminated element always experiences initial radial tensile stresses across the timber fibers. Notably, they reach their maximum in the glue seams in the middle of the section. The maximum tangential stresses occur in specific glue seams within the package layers: tensile stresses $\sigma_{\theta\_out}^{init}$ occur on the convex side of plank 1, compressive stresses $\sigma_{\theta\_in}^{init}$ occur on the concave edge of plank *n*. The maximum shear stresses τ_i^{init} occur in the glue seams of the layers with minimum curvature radii, where the curved sections gradually transition into the straight sections. Apart from the glue seams, the shear stresses also occur in the lamellae layers themselves.

During the gluing process, each layer (aside from the faces of the outer lamellae) is dipped in glue, which also acts as a plasticizer. This results in plasticization, to a certain degree. For reference: the plasticization of timber fibers is a technique commonly used for making bentwood furniture. Some of the most commonly known plasticizers include urea, phenol formaldehyde resin, and other substances (Gorshin, 1979). On the one hand, this makes it easier to bend the lamellae and achieve the necessary curvature; on the other hand, this reduces the stresses in the layer's outer fibers (as deep as the glue reaches). This diminishes the force that is driving the curved laminated element to straighten out after the pressing-out stage. Thus,

$$M_{pl}^{f} = k_{pl}\cdot k_E \cdot \frac{E\cdot b\cdot \delta^2}{12}\ln(1+\frac{n}{\beta_1}) \ ,$$

where k_{pl} is the coefficient that accounts for the reduction of the elastic forces that straighten out the lamellae (caused by glue plasticization in the most stressed outer faces). We shall roughly assume that $k_{pl} \approx 0.8 \div 0.9$. This assumption may later be adjusted through experimentation. We can approach the plasticization effect as the reduction of the elasticity modulus at stage 1 of production.

We shall also assume that, once the glue hardens during stage 2, the timber regains its elastic properties, while retaining its new strained state. Subsequently, after the curved laminated structure spends some time in storage, the inner stresses relax. Gordon (1973) obtains, for the purpose of simulating the relaxation process, approximate experimental values of the timber's elasticity modulus reduction coefficient k_E (along the fibers), depending on the relative radius of the plank curvature β_i and the time of the structure being held in a curved state. We shall adopt this coefficient for tangential stresses in the first approximation as $k_E \approx 0.9$. Furthermore, if we take into account the data from Regulation SP 64.13330.2017, cl. 6.10 and cl. 6.11, we can also depict the relaxation process as the reduction of the elasticity modulus by the $m_{lt.E} \approx 0.9$ long-term strength coefficient. In that case, we can formulate the following equations (Figs. 5 and 6) for the radial and tangential stresses after stage 2 (pressing out):

- maximum **radial** tensile stresses in the middle of the beam:

$$\sigma_r^{(2)} = \frac{M^f}{4\cdot\beta\cdot W} = \frac{1}{4\cdot n}E\frac{\ln(1+\frac{n}{\beta_1})}{2\beta_1+n-1} \ . \quad (10)$$

- **tangential** tensile stresses along the **inner** edge:

$$\sigma_{\theta\_in}^{(2)} = k_E\cdot m_{lt,E}\cdot\frac{M^f}{W}(1+\frac{1}{2\beta}) = k_{pl}\cdot k_E\cdot m_{lt,E} \cdot\frac{E}{n^2}\left(\frac{1}{2}+\frac{1}{4\beta}\right)\cdot\ln\left(1+\frac{n}{\beta_1}\right) \ . \quad (11)$$

- **tangential** compressive stresses along the **outer** edge:

$$\sigma_{\theta\_out}^{(2)} = k_E\cdot m_{lt,E}\cdot\frac{M^f}{W}(1-\frac{1}{6\beta}) = k_{pl}\cdot k_E\cdot m_{lt,E}\cdot\frac{E}{n^2}\left(\frac{1}{2}-\frac{1}{12\beta}\right)\cdot\ln\left(1+\frac{n}{\beta_1}\right) \ . \quad (12)$$

Based on the dependencies that we found, we assessed the initial stress-strain state of the curved laminated element in the Mathcad-15 software, using the parameters that tend to occur frequently in a multi-layer curved laminated element.

For instance, given the data provided in Regulations SP 64.13330.2017, Table C.3, we obtain the following stage 1 data for pine lamellae with the design elasticity modulus along the timber fibers $E_d = E_s\cdot k_{pl}\cdot k_E\cdot m_{lt.E} = 5.69$ GPa, shear modulus along the fibers G = 0.35 GPa, layer number n = 10, layer thickness δ = 30 mm, layer width b = 150 mm, and the relative radius of the first lamella β1 = 200:

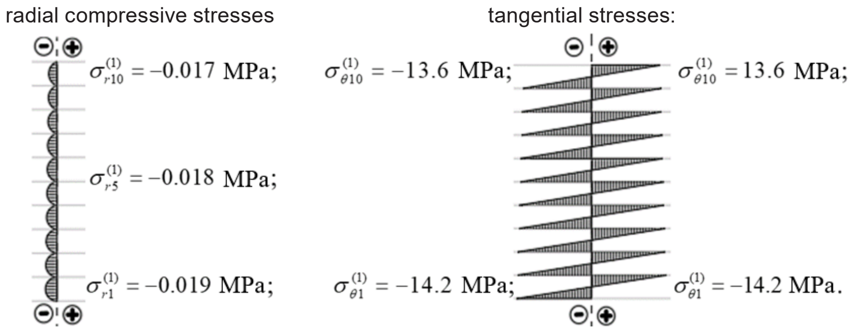

Figure 7. Numerical values of stresses during production stage 1

Stage 2 data:

Radial tensile stresses; Tangential stresses; Shear stresses;

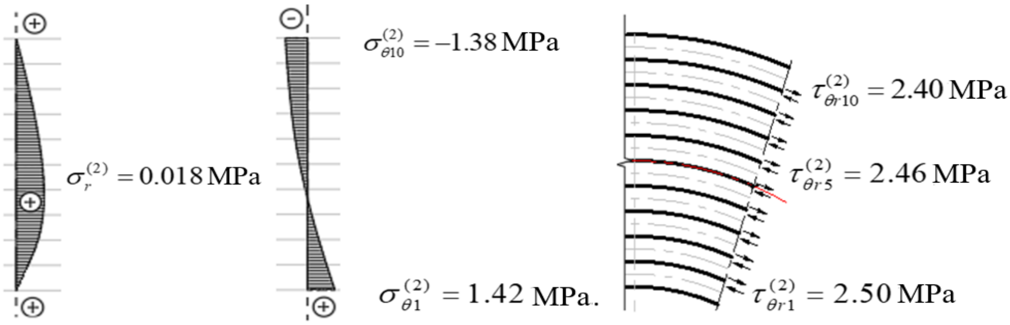

Figure 8. Numerical values of stresses during production stage 2

The total initial stress shall be as follows:

radial stresses; tangential stresses; shear stresses

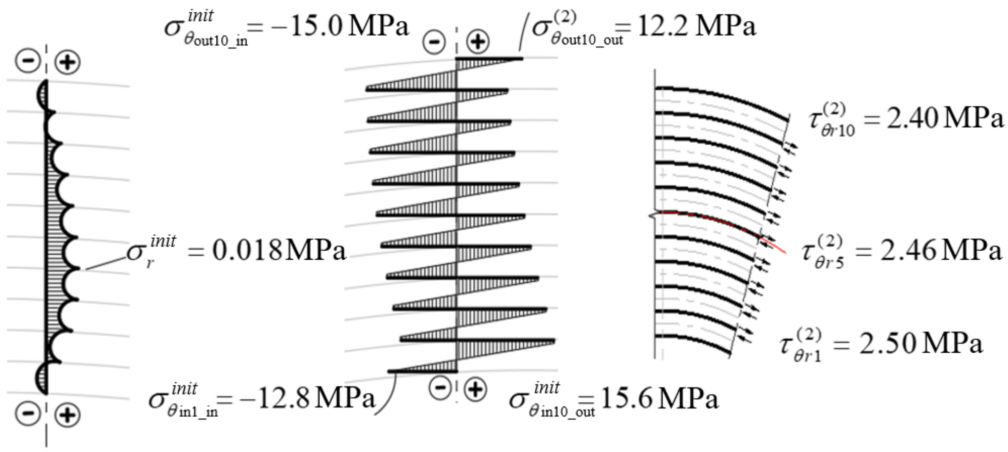

Figure 9. Total initial stress after pressing-out

The stress values shown in Figures 7, 8 and 9 approach the threshold of the respective values of design ultimate timber resistance. We must further note that the existence of tangential, radial, and shear stress also leads to the occurrence of "principal stresses", which affect the structure at a certain angle in relation to those timber fibers where the wood strength is significantly reduced. This fact is also overlooked in guidelines for analyzing curved laminated structures and merits further study.

Results and Discussion

In light of the above, we can conclude that the limit state of the curved laminated section of the wooden structure depends on the nature of stress that will cumulate with the initial stress during operation. This impact may cause different stress states within the curved section. Depending on the stress type and direction, the prestressed curved laminated element may be subjected both to straightening forces and bending forces that increase the curvature.

The aforementioned coefficients are recorded in Table 12 of Regulations SP 64.13330.2017, "Compression and Bending" and "Tension"; however, they only reflect the stress that is accompanied by the bending of curved sections. For instance, in the case of curved laminated cornice joints of three-joint articulated frames (Serov et al., 2011), where external load almost always creates a force that increases the section curvature, this coefficient is applied to tangential stresses. In this instance, the external load-related stresses along the outer and inner radii have the same direction as the initial stresses, and therefore both types add up. For radial stresses (in this case, stresses that are caused by external load and compress the element across the fibers), this coefficient is not needed, as the initial hazardous radial tensile stresses either decrease or convert into compression.

That said, if the curved segments of the laminated structures experience "straightening" forces, the nature of the stress-strain state changes entirely. In situations like this, the m_{bend} coefficient provided in Regulations SP 64.13330.2017 is not applicable. Specifically, many well-known studies (American Wood Council, 2015; Maki and Kuenzi, 1965; Riberholt, 1979) show that in many boomerang-type

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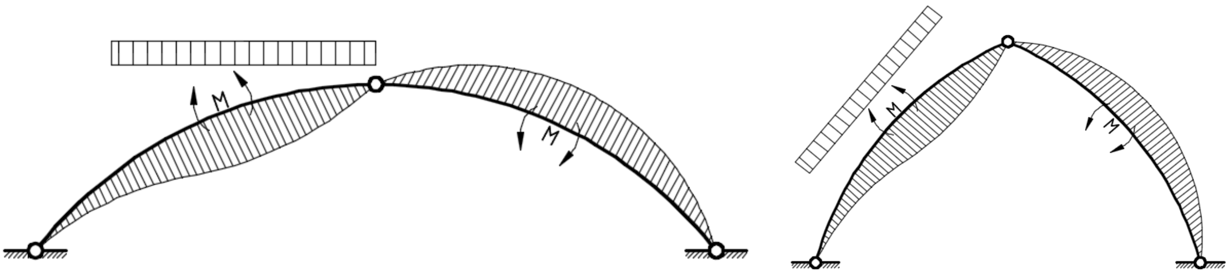

Figure 10. Bending moments that cause the straightening-out effect in the left semi-arches

curved laminated beams experiencing straightening forces, tangential stresses are opposite in sign to the initial tangential stresses, while the radial tensile stresses cumulate with the initial radial tensile stresses. In other words, the impact of tangential stresses on the structure's overall SSS decreases, while the role of radial tensile stresses across the fibers, by contrast, increases substantially. In this case, coefficient m_{bend} must exceed 1.0 for tangential stresses and be less than 1.0 for radial stresses. However, there is no m_{bend} coefficient for radial stresses across the timber fibers.

Another fact that is worth noting is the possibility of designing curved laminated beams with the convexity facing downward.

For such designs, the m_{bend} coefficients must have other values, properly reflecting the resulting stress.

Aside from curved beams that are subjected to a transverse load force that straightens them out, construction practice often deals with compressed bent structures that experience "unbending" stress. For instance, such popular solutions as curved laminated arches with a depressed, pointed, or circular outline, tend to undergo compression (accompanied by bending) during operation. That said, multiple calculations show that when the structure is subjected to unilateral load (for instance, caused by the rain and/or snow), the normal compression force *N* is accompanied by bending moments *M*, which straighten out (unbend) the curved laminated arches.

It is also interesting to note that, in situations like this, the stress from the normal compression force N amounts to less than 10–15% of the stress from bending moment M. Thus, what we are left with are compressed bent curved elements that operate under an immense unbending force. But such a force always creates radial tensile stresses across the timber fibers. In (Schmidt, 1980), we observed that a test of compressed bent laminated elements with a large curvature radius was accompanied by destruction, caused by radial tensile stresses across the fibers. Such initial stress exists even in structures with a small curvature radius. And if it cumulates with the unbending force, the likelihood of destruction caused by tangential stresses decreases, while the likelihood of destruction caused by radial tensile stresses across the fibers increases. Furthermore, if such structures also have cracks due to loss of moisture, radial stresses are only going to make these cracks broader.

Conclusions

This preliminary study has rationalized the need for analyzing curved laminated wooden elements while using the rules that differ from those applicable to straight elements, accounting for the direction of the inner forces *M, N* and *Q*, and for the prestress during production.

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НАПРЯЖЕННО-ДЕФОРМИРОВАННОЕ СОСТОЯНИЕ ДЕРЕВЯННЫХ ГНУТОКЛЕЕНЫХ ЭЛЕМЕНТОВ ПРИ ИЗГОТОВЛЕНИИ

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Аннотация

Напряженно-деформированное состояние (НДС) деревянных гнутоклееных элементов может значительно отличаться от НДС прямолинейных клееных деревянных элементов не только по степени кривизны, но также и по параметрам изготовления и направления действующих нагрузок при эксплуатации. При изготовлении криволинейного элемента путем склеивания изогнутых досок (ламелей) конструкция приобретает внутренние начальные напряжения, вызванные стремлением отдельных гнутых ламелей вернуться в прямолинейное состояние. После изготовления в элементе возникает неравномерное начальное напряжённое состояние, которое изменяет его прочностные свойства в различных структурных направлениях по отношению к волокнам древесины. В дальнейшем это влияет на напряжённое состояние конструкции от действующих внешних нагрузок. Этот факт остается не вполне освещенным в российских и зарубежных нормах (СП, EuroCode 5, DIN) и явился предметом исследований автора. **Методы:** С этой целью рассматривается математическая модель процесса формирования НДС гнутоклееных деревянных элементов, который условно разбит на две стадии: 1-ую – гнутья отдельных ламелей, их склеивания и запрессовки, 2-ую - распрессовки гнутоклееного пакета. Так создается начальное преднапряжение в виде комбинации тангенциальных, радиальных и касательных напряжений. **Результаты:** Получена графическая картина суммарного преднапряженного состояния на 1-й и 2-й стадиях, которая позволяет прогнозировать напряженное состояние гнутоклеёных деревянных конструкций при переменных эксплуатационных нагрузках. **Обсуждение:** Указывается на влияние процессов релаксации начальных напряжений, которые следует дополнительно исследовать. В зависимости от направления и величины эксплуатационных нагрузок гнутоклееный участок конструкции может «разгибаться» с уменьшением кривизны или наоборот далее «сгибаться» с ее увеличением. Это не вполне корректно учитывается в нормах проектирования деревянных конструкций и требует изучения.

Ключевые слова

Гнутоклееный деревянных элемент, процесс изготовления криволинейных деревянных конструкций, начальное преднапряженное состояние, сочетание начального преднапряжения с напряжениями от эксплуатационных нагрузок.

REVIEW OF THE ANALYTICAL ASSESSMENT METHOD OF FINDING THE SEISMIC AND EXTREME LOAD RESILIENCE OF SHEAR LINKS

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Abstract

Introduction: This paper reviews the analytical method of assessing the seismic and extreme load resistance of buildings with a complex macrostructure that includes elastic-plastic inserts operating in shear. **Methods:** We analyze a number of studies that rationalize the choice of models for simulating complex elastic-plastic deformation in a mechanical system with several degrees of freedom, as well as studies that review the durability and resilience of buildings with a complex macrostructure based on non-linear shear links when subjected to dynamic and extreme impact. We also consider the methods of structural analysis regarding buildings with elastic-plastic inserts, accounting for the plastic hinged joints of metal frames. **Results:** We apply the analytical method to linear and non-linear systems with *n* degrees of freedom. We propose a mathematical equation that describes the nature of shear link response to seismic and extreme loads. Our method makes it possible to obtain an analytical solution for structures with proportionate and disproportionate damping by using the direct integration algorithm. **Discussion:** Most structures with a broad range of construction material properties require a disproportionate damping model. In this study, we solve equations by using the direct integration algorithm based on disproportionate damping. Under high dynamic load, the reinforcement of shear inserts operates in a plastic state.

Keywords

Analytical assessment method, seismic load, extreme impact, elastic-plastic insert.

Introduction

Structural integrity can be preserved through the use of elastic-plastic inserts (EPIs), which exhibit elastic-plastic properties and ensure that the expansion joints remain flexible enough to withstand dynamic and extreme impact. EPIs reduce the risk of destruction and buckling in buildings and structures that are subjected to seismic activity and extreme conditions. By adjusting the EPI stiffness characteristics, one can control the dynamic parameters of buildings and structures. There have been some studies on the stiffness characteristics of such inserts in buildings with a complex macrostructure, but an examination of Russian and foreign published research has not revealed any instances of reviewing the analytical methods of assessing how EPIs impact the stress-strain state of buildings with a complex macrostructure when subjected to seismic and extreme load. Therefore, it would be highly relevant to study the methods of assessing the stress-strain state of buildings having a complex macrostructure with elastic-plastic inserts in dynamic or extreme conditions.

In (Rutman, 2013), Professor Yu. L. Rutman looks at the ways in which hardening is accounted for within elastic-plastic macro models; whereas in (Rutman, 2012), he studies a model of complex elastic-plastic deformation, applicable to mechanical systems with several degrees of freedom. Rutman's students also propose solutions for determining the parameters of a force diagram for structural elements subject to plastic deformation (Rutman et al., 2007). They deploy a macro model method for assessing the maximum earthquake magnitude that frame structures can withstand (Nidzhad, 2014) and analyze the results of dynamic elastic-plastic analysis based on models with both one and several degrees of freedom (Simbort, 2011).

In turn, Professor V. I. Pletnev and his circle were interested in the issues of dynamic and extreme impact on the durability and resilience of buildings with a complex macro structure based on non-linear shear links (Golykh et al., 2010, 2011; Samsonov, 2003; Smirnov, 2008). Direct integration-based solutions of equations describing structures with disproportionate damping are provided in (Samsonov, 2003). The experiment description and result analysis may be found in (Omori, 1900; Pletnhov and Nguyen, 2011).

Another study (Nguyen and Kondratieva, 2013) demonstrates, through analytical and numerical methods, how elastic-plastic inserts impact the free vibration of a polyhedral shell. A study by Sanchez-Ricart and Plumier (2008) contains a force analysis, accounting for the plastic hinged joints of metal frames.

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Finally, several more studies (Bataev et al. 2016; Chepurnenko et al., 2016, 2019) examine an analytical method of assessing stresses in reinforced-concrete slabs and wall panels with account for creep.

Methods

The main focus of all researchers is structural resilience. High-rise buildings are sensitive to seismic activity, which causes major displacements and creates substantial stress within the load-bearing structures. This issue can be resolved through installing damping tools: special elastic-plastic inserts (Fig. 1) that will allow the building to remain usable even in extreme conditions. As the segments of the building shift significantly in relation to each other, the building will continue to function and retain its general resilience through the redistribution of forces.

There are many known versions of damping tools, which require analysis and clear recommendations for usage under specific conditions. In this paper, we take a look at the EPIs represented in a diagram in Figure 2. The size and shape of elastic-plastic inserts depend on the extent and direction of the current load, as well as on the geometrical parameters and stiffness characteristics of buildings and structures. Such inserts are going to act as dampers in dynamic and extreme conditions.

Under high dynamic load, the reinforcement of shear inserts operates in a plastic state.

When describing the shear insert operation, it is important to find a mathematical equation that would properly characterize the studied object. We propose the following analytical solution for bearing seismic load:

$$M\ddot{u} + C\dot{u} + Ku = -ME_x\ddot{X}_0(t), \quad (1)$$

where $\ddot{u}$ is the acceleration vector, $\dot{u}$ is the speed vector, u is the localized mass displacement vector; *M* is the mass matrix; *C* is the dissipation matrix; *K* is the stiffness matrix; *Ex* is the modulus of elasticity; $\ddot{X}_0(t)$ is the soil acceleration.

We can solve equation (1) within the three-dimensional coordinate system, accounting for the three components of seismic acceleration $\ddot{X}_0(t); \ddot{Y}_0(t)\, 8\, \ddot{Z}_0(t)$:

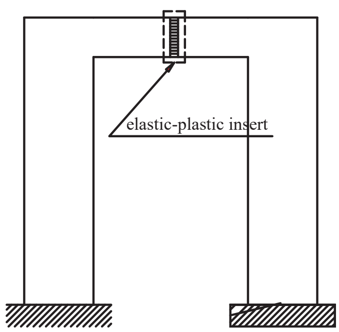

Figure 1. Diagram of a high-rise building with an EPI

$$M\ddot{u} + C\dot{u} + Ku = -M(E_x\ddot{X}_0(t) + + E_y\ddot{Y}_0(t) + E_z\ddot{Z}_0(t)), \quad (2)$$

where $E_x(t); E_y(t) and E_z(t)$ components are also defined within the three-dimensional coordinate system.

If the system is linear, we can apply the eigenfunction expansion method. It can be briefly described as follows:

1. Create the initial matrices: dissipation matrix *C*, stiffness matrix *K*, and mass matrix *M*; 2. Find the eigenfrequencies and eigenmodes of the system.

Note that we do not account for damping when determining the eigenfrequencies and eigenmodes. The frequencies and modes are viewed as eigenvalues:

$$(K - \omega^2 M).\theta = 0;$$

$$\det(K - \omega^2 M) = 0.$$

Eigenvector with the mass matrix:

$$\varphi_k^T M \varphi_k = 1.$$

3. Find the normal components of the system.

In a forced vibration description, the displacement amplitude vector is determined through coordinate transformation:

$$u = \Phi q;\ u = \Phi q; \quad (3)$$

where Φ is the transformation matrix:

$$\Phi^T = (\phi_1, \phi_2, ... \phi_n). \quad (4)$$

We shall now substitute (3) in (2) and, accounting for (4), arrive at the following conclusion:

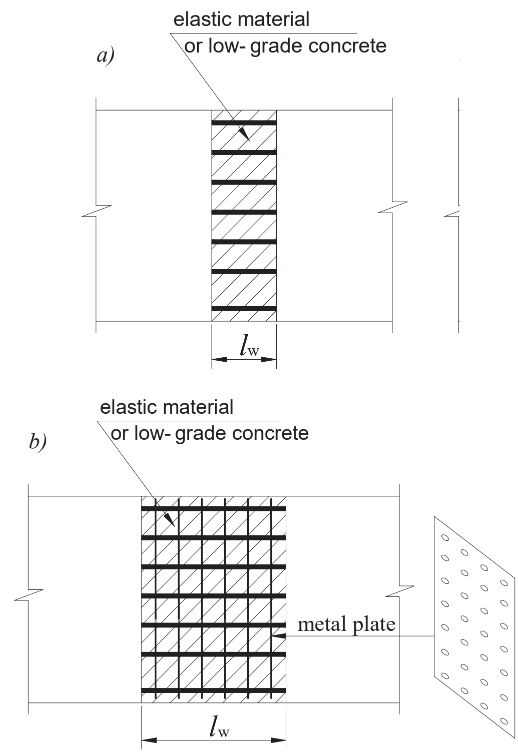

Figure 2. Diagrams of elastic-plastic inserts: a) for small L_B values; b) for large $L_B$values, with longitudinal reinforcement and transverse metal plates and rubber buffers

$$\Phi^T M\Phi\ddot{q} + \Phi^T C\Phi\dot{q} + \Phi^T K\Phi q = -\Phi^T ME_x \ddot{X}_0(t). \quad (5)$$

Let us now apply the orthogonality condition:

$$\Phi^T M\Phi = I; \quad (6)$$

After several mathematical operations, we find:

$$\Phi^T K\Phi = \omega. \quad (7)$$

It is possible to meet the following conditions:

$$\phi_i^T C\phi_j = 0\ (i \neq j);\ \ \phi_i^T C\phi_j = 2\beta_i\omega_i\ (i = j). \quad (8)$$

When conditions (8) are met, the system of equations (1) is going to branch into *n* independent equations. Each of them will be defined by generalized coordinate q_i, corresponding to vibration mode *i*:

$$\ddot{q}_i + 2\beta_i\omega\dot{q}_i + \omega_i^2 q = -\Gamma_i \ddot{X}_0(t); \quad (9)$$

where β_i is the relative damping value for vibration mode *i*,

$-\Gamma_i = \phi^T ME_x$ is the modal contribution factor.

Therefore, if we are dealing with a linear system, the solutions of the motion equations for systems with n degrees of freedom shall serve as a basis for resolving the linear oscillator problem.

4. Integrate the systems of equations.

In order to solve equation (9), we used Duhamel's integral:

$$q_i(t) = \frac{\Gamma_i}{\omega_i}\int_0^t \ddot{X}_0(\tau)\,\mathrm{e}^{-\beta_i\omega_i(t-\tau)}.\sin\omega_i^D(\mathrm{t}-\tau)\,\mathrm{d}\,\tau; \quad (10)$$

where $\omega_i^D = \omega_i\sqrt{1-\beta_i^2}$ – is the eigenfrequency (damping included).

Determining the support reaction in the structure's design model requires solutions for all n equations. We tracked the displacement of node points by superposing system reactions to all vibration modes.

5. Find the displacement in specific nodes.

The amplitude of vibration mode j can be found through the following equation:

$$u_i(t) = \phi_i.q_i(t). \quad (11)$$

6. Determine the force in the elements of the reference system.

Bearing in mind the construction mechanics principle, which dictates that all forces are independent, we define "force" as a sum of forces that are caused by inertia and external impact:

$$S_k(t) = S_{kF}.F(t) + S_{k1}.J_1(t); \quad (12)$$

where S_{kF} is the force in the k section, caused by force *F* = 1, S_{kl} is the force in the *k* section, caused by inertia J_j = 1.

Equation (12) written in displacements shall look as follows:

$$S_k(t) = S_{kF}.F(t) + b_{k1}.u(t); \quad (13)$$

where b_{k1} is the force matrix in the *k* section, caused by unit displacement.

If the goal is to make our calculations more precise, accounting for dissipation, then equation (13) will look as follows:

$$S_k(t) = S_{kF}.F(t) + [b_{k1} + \frac{S_{k1}.^2{}_1.\dot{u}(t)}{u(t)}].u(t); \quad (14)$$

In equation (14), damping is described through an increase of stiffness.

Results

The process of determining forces is based on variables, which makes it even more challenging. However, for assessing the seismic stability of buildings, it is enough to find the maximum force: $S_k max$.

The solution is simplified (without losing accuracy) if the system of differential equations is subjected to eigenmode expansion:

- integrating differential equations that describe mode *j* of motion equations is simpler than integrating the original systems of equations;
- it is possible to achieve the desired accuracy level by finding not all *n* eigenmodes, but only the modes from this interval: *S* < *n*.

Discussion

The method described in this paper is applicable not only to linear systems but also to systems where the dissipation matrices meet condition (8).

Assuming that vibration damping is proportionate to mass and stiffness, Rayleigh devised an equation where the C matrix from equation (8) looks as follows:

$$C = \bar{a}.M + \bar{b}K, \quad (15)$$

where $\bar{a}$ и $\bar{b}$ are the proportionality coefficients for vibrations with different frequencies, dependent on the damping coefficient β_i .

As equation (5) allows for the eigenfunction expansion method, this means that each member of equation (5) will be expressed as a diagonal matrix.

The assumption that damping is proportionate is valid in some cases. But most structures with a broad range of construction material properties may require a disproportionate damping model. When we analyze structures together with their foundation, the foundation accounts for most of the damping. Therefore, we propose using damping matrices with different coefficients $\bar{a}$ и $\bar{b}$ for different structure parts. In this case, the damping matrix is not compliant with equation (8).

Conclusions

We have proposed a mathematical equation that describes the nature of shear link response to seismic and extreme loads.

Our method makes it possible to obtain an analytical solution for structures with proportionate and disproportionate damping by using the direct integration algorithm.

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АНАЛИЗ МЕТОДИКИ АНАЛИТИЧЕСКОГО РАСЧЕТА СДВИГОВЫХ СВЯЗЕЙ НА СЕЙСМИЧЕСКИЕ И ЭКСТРЕМАЛЬНЫЕ НАГРУЗКИ

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Аннотация

Статья посвящена анализу аналитического метода расчета на сейсмические и экстремальные воздействия зданий сложной макроструктуры с упругопластическими вставками, которые работают на сдвиг. **Методы:** В статье приведен анализ работ, посвященных выборам моделей сложного упругопластического деформирования механической системы с несколькими степенями свободы; прочности и устойчивости зданий сложной макроструктуры с нелинейными сдвиговыми связями при динамических и экстремальных воздействиях; методикам расчета зданий с упругопластическими вставками с учетом пластических шарниров стальных каркасов. **Результаты:** Аналитический метод применен для линейных и нелинейных систем с *n* степенями свободы. Предложено математическое выражение, описывающее характер работы сдвиговых связей на сейсмические и экстремальные нагрузки. Методика позволяет получить аналитическое решение с использованием алгоритма прямого интегрирования для строительных конструкций с пропорциональным и непропорциональным демпфированием. **Обсуждение:** Для большинства сооружений с широким диапазоном свойств строительных материалов необходимо применение модели непропорционального демпфирования. Получено решение уравнений с использованием алгоритма прямого интегрирования с непропорциональным демпфированием. При больших значениях динамических нагрузок арматура сдвиговых вставок работает в пластической стадии.

Ключевые слова

Аналитический метод расчета, сейсмическая нагрузка, экстремальное воздействие, упругопластическая вставка.

Urban Planning

URBAN PLANNING MODEL OF WATERFRONT RECREATION ZONES IN THE ALTAI MOUNTAIN REGION

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Abstract
Introduction: Over the past quarter of a century, the issue of urban development within regional settlement systems has not been a priority for most policy-makers and professionals. Much more attention has been focused on the issues arising from the expansion of major metropolises: Moscow, St. Petersburg, Yekaterinburg, Kazan, and several others (seven in total). In the meanwhile, the urban development of unique natural landscapes in other regions has been progressing on its own, without major supervision or proper attention from the professional community. For instance, the pristine land along Lake Baikal has undergone urban development without proper planning documentation; vast areas in the Irkutsk Region have been sold off for logging; and the Altai Territory and the Republic of Altai are seeing intensive development of unplanned recreation hubs. **Purpose of the study:** The study is aimed to create an urban planning model for unique natural landscapes. **Methods:** We used such methods as multi-factor analysis, photographic footage, opinion poll, and graphical modeling. **Results:** Out study results in an original model that illustrates the optimal location of new recreation hubs, mindful of preserving the unique environmental qualities of the natural landscape.

Keywords
Urban development, landscapes, recreation zones, environment, sustainable development.

Introduction

Bearing in mind that urbanization is a cyclical process and the urban development vector might shift away from metropolises to dispersed regional settlement systems in the 21st century, there is a need for new models that would create a planning layout for major spaces and tie together the goals of preserving the local environment, on the one hand, and ensuring urban development, on the other hand (thus resolving the conflict between the environment and the economy). We recommend resolving the above by considering one of the most typical examples. The example in question is an area that lies in Siberia's southern settlement region, within the boundaries of the Republic of Altai (Chemalsky municipal district). It stretches along the river Katun, which forms a natural compositional axis. The river is the key terrain-shaping factor. Its basin is flanked by the upper peaks of the watershed mountain ranges, which have smaller rivers and streams flowing down them, feeding the Katun. This is the reason why we have decided to draw the boundaries of the target territory along the peaks of the watershed: the eastern boundary is the top of the Iolgo ridge; the western boundary is the Seminsky ridge; the southern boundary is the Kuminsky ridge and the river Chemal; and the northern boundary is the administrative district line (Fig. 1).

The territory possesses unique natural properties that facilitate outdoor recreation, along with multiple landmarks that appeal to vacationers and wellness enthusiasts: the Tavdinskiye caves, the Kamyshlinsky waterfall, the downstream Katun rapids, the Chemalo-Katunskaya dam (the oldest dam in Russia), the isle of Patmos and its monastery, the unique mountain lake Manzherok, the Che-Chkysh waterfall, the Karakol mountain lakes, rock art, and much more (17 major natural landmarks in total). The intensive development of recreational activity—from sports tourism and traveling by water and by car to educational tourism, from long relaxing getaways to short active field trips—has turned this land strip along the Katun banks into the "red line" of the Altai Mountains, attracting investments into the urban development of the valuable waterfront areas that can be used for even better recreation.

Several fairly large-scale projects have already been designed for the territory; they have involved the construction of various recreation complexes: Turquoise Katun (the left bank of the river Katun, from the Altai Territory side), an almost entirely uninterrupted chain of camping sites, vacation centers, and health resorts within close reach of the river bank, and the Altai Valley complex, located 25 km south of Gorno-Altaysk. Altai Valley was a major vacation facility that included a giant artificial lake, parallel to the Katun; its expected capacity was 94,000 people. However, this project is testimony to the disadvantages of super-dense recreational urbanization: it overloaded the surrounding natural landscape and was eventually shut down when its untreated wastewater polluted the river. With that in mind, we believe that the study's target territory is, to a certain extent, problematic, due to the dense recreational development that overburdens the waterfront area. This is caused by the presence of massive transportation and communication axes, the Chuya and Chemal Highways, which pass along the narrow bottom of the Katun basin between the mountain ridges and create links between Novosibirsk, Barnaul, Biysk, Gorno-Altaysk (the capital of the Republic of Altai), and the local administrative center, Chemal. Easy access by transport encourages investors to pour more money into the urban development of the unique waterfront areas, which are perfect vacation spots but have a fragile ecosystem.

The key problem uncovered in this study is the contrast between the investors and developers' motivation to explore the most appealing recreation spots along the waterfront and the need to preserve the landscape for tourists and vacationers in the face

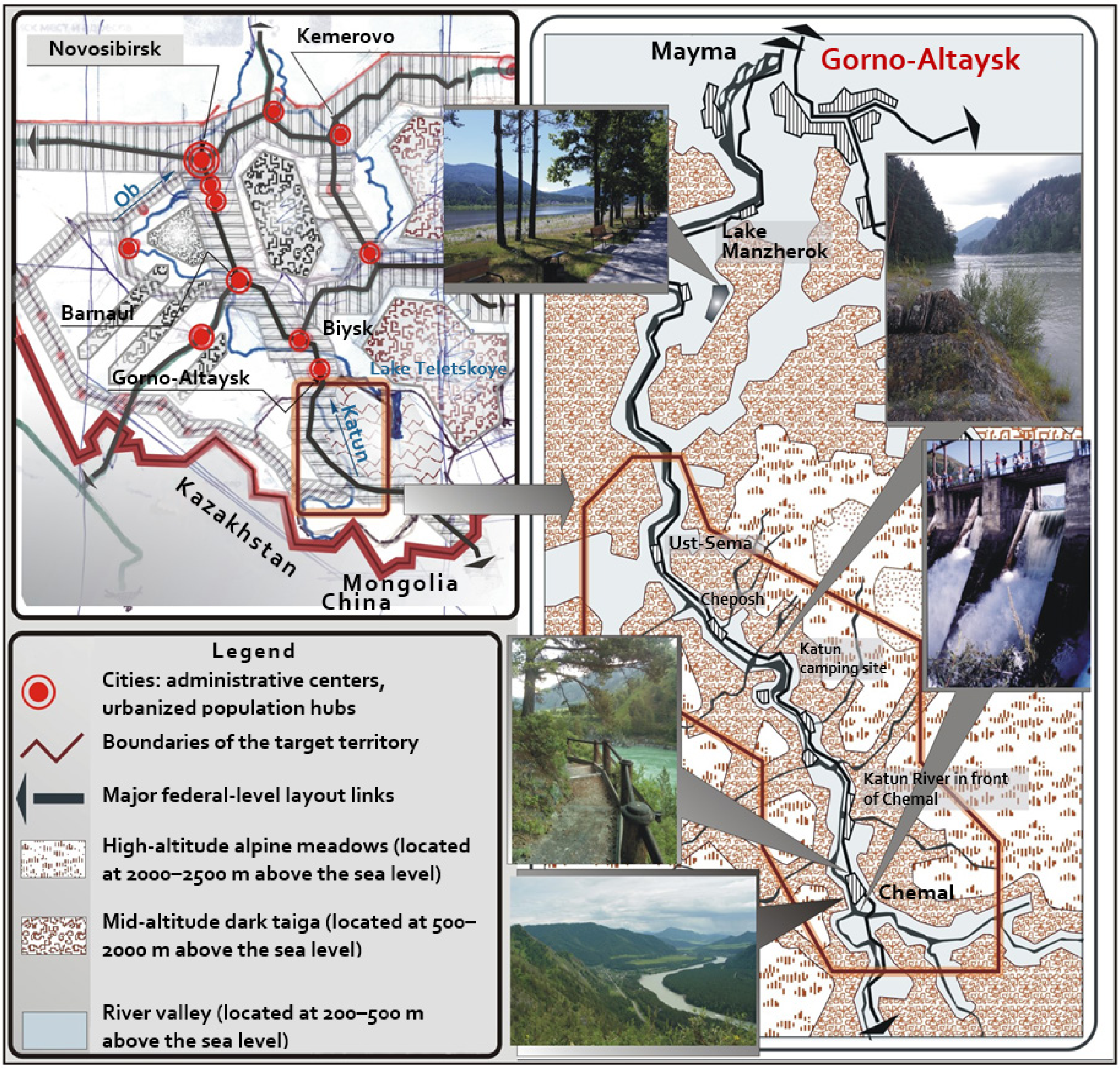

Figure 1. Location and boundaries of the target territory (all photos were taken by the authors)

of rapid degradation caused by urban development. This urban planning issue—the clash between economic feasibility and environmental integrity—is accompanied by a conflict of interest that concerns, on the one hand, investors and developers and, on the other hand, the authorities in charge of preserving the unique natural recreation areas.

Our study's **goal** is to create an urban planning model for waterfront recreation zones that would help resolve these conflicts.

We propose the following **research hypothesis**: new recreation hubs emerge in intersection points of two types of urban planning axes, transportation axes and natural axes. If we trace the transportation axes and pinpoint where they intersect with the natural axes (rivers), it will be easy to determine where new recreation hubs emerge and develop.

The **object** of our study is waterfront recreation zones.

The **subject** of our study is the architectural and urban planning layout of the aforementioned waterfront recreation zones.

The following tasks shall be completed:

- making a multi-factor assessment of the target territory, for the purpose of determining the prerequisites and limitations for its urban development;
- analyzing the current methodological approaches to the architectural and urban planning layout of similar recreation zones;
- creating an architectural design and urban development model of the target territory.

The **methods** selected for this study include: detailed assessment, photographic footage, opinion poll, and graphical modeling.

Results and discussion

After a detailed assessment of the target territory, we single out segments with high potential for building recreation complexes. The assessment includes an on-site inspection: photographic footage and mapping of the terrain features and sites discovered, as well as the collection of cadastral data (usage permits, purpose), which need to be compared with the officially approved urban planning documentation (urban planning layout of the Chemalsky District) (Ministry of Economic Development of the Russian Federation, Federal State Information System on Territorial Planning, 2010). The urban planning layout includes a potential long-term recreation zone along the Katun. The transit zones and zones for short-term recreation are planned further inland, along smaller rivers (Chemal, Elekmonar, Uznezya, Kuba, and Anos). The boundary segments of the area are meant to be protected zones where recreational development is restricted.

The Chemal area is currently the most interesting part of the territory. It is 4.5 km^2 in size, excluding settlements within the narrow strip that is 30 km long and up to 500 m wide, stretching between the Chemal Highway and the Katun bank line. Over the past ten years, this segment has exhibited a maximum density of various recreation and tourism facilities (Fig. 2).

Out of the several hundred development sites located between the Katun river crossing in the Ust-Sema village and the local administrative center Chemal, we have singled out 34 relatively large facilities (eco hotels, camping sites, vacation centers) that provide accommodation and services for tourists and have their own land plots. All of the facilities that we have inspected share a very specific location feature: their land plots fall within the river bank line and the water protection zone. While their official purpose, as per cadastral documents, is "for building recreation facilities" and "positioning sites (territories) intended for recreation", all of them are situated within specially protected natural areas. The total size of all the facilities' land plots is 70.9859 ha, or 0.7 km^2, which is 15% of the entire target territory (4.5 km^2). We have also calculated the total capacity of all the recreation facilities, which varies between 9 (Dacha in Uznezya hotel) and 225 beds (Nika camping site). This has allowed us to determine the actual recreation load on the area: over fifteen hundred tourists within a 0.7 km2 space. The total capacity is 1667 people during the peak summer season. Therefore, the peak recreation load on the waterfront area is 23 people per hectare, which exceeds the load recommended by ecologists (7 people per hectare) (Pavlova 2015) more than threefold. Furthermore, the tourist influx dynamics only keep growing. The overloaded natural landscapes along the Katun, especially given the territory's very modest size, keep losing their recreational appeal, as the Chemal destination is transforming into an uninterrupted urbanized development area, and the buildings block out access to the waterfront. This calls for an urgent solution.

The next stage of our detailed assessment is to uncover the natural and geological factors behind the emergence and development of recreation-centric urbanization hubs, including such tourism complexes as Turquoise Katun, Tursib, Manzherok, Chemal, and others. We have noted a specific feature, shared by locations where recreation facilities are packed together most densely: the largest recreation-centric urbanization hubs emerge at the confluence of the Katun with smaller mountain rivers (such as Uznezya, Elekmonar, and Chemal), where the rivers also intersect a major transportation axis, for instance, the Chemal Highway.

In 2009, one of the authors (N. V. Sergeyeva) also applied the opinion poll method. The poll allowed us to make conclusions regarding the reasons why the tourist influx tends to gravitate towards territories with a specific terrain type. Visual diagrams make it possible to determine the most preferable types of recreation and natural surroundings, depending on the tourists' income, job, and age (Pomorov and Morozova, 2009). Surveys have helped identify the frequency of visiting the Altai Mountains region (1–2 times a year). The stay duration ranges between three and seven days (67% of respondents). Notably, the visit frequency rises proportionately to the average per capita income. The most popular season for vacationing in the Altai mountains is summer. Many respondents (43%) travel with their families, but most prefer small tourist groups (57%). Interestingly, the predominant age group is young people under 29, who go vacationing with their friends. The preference for family vacations grows in older age groups. When it comes to vacation and tourism types, active recreation is the most popular option (58%). Educational tourism comes second (20%). Most visitors prefer to spend their vacation in the woods, on the bank of a mountain stream (56%), enjoying a pristine natural landscape (mountains, woodlands, and water) in peace and quiet, with no other people nearby, and preferably far away from populated areas. Those tourists that opt for this type of vacation are vehemently opposed to living in large dormitories, preferring seasonal or year-round cottages. The third most popular option is a comfortable one- or two-story accommodation facility with few rooms.

The current layout of the vast majority of facilities that we have studied has a distinct peculiarity: it is linear, parallel with the bank line. The year-round core facility usually has two promenades branching

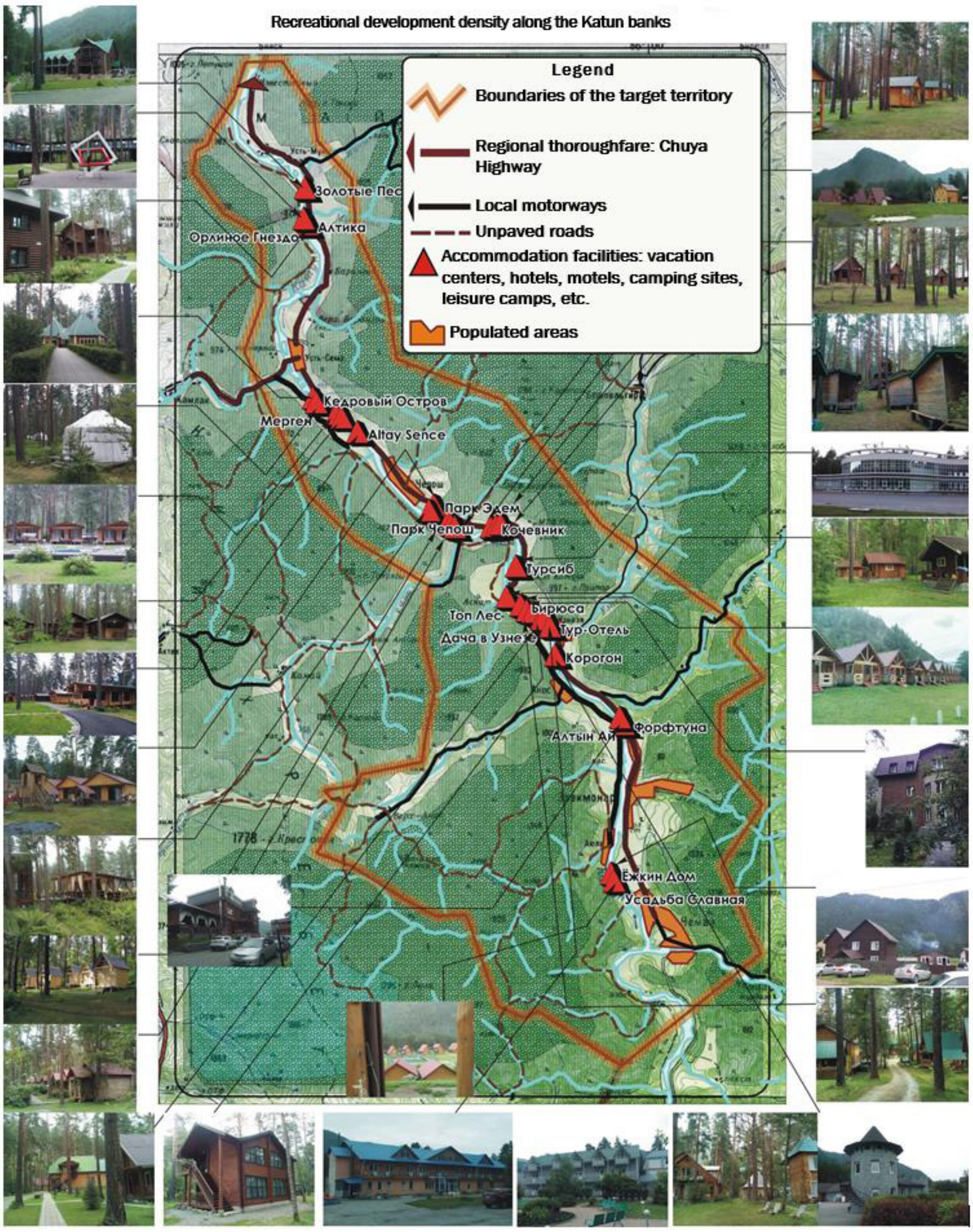

Figure 2. Development density along the Katun bank line in the Chemalsky District, Altai Mountain region (all photos were taken by the authors)

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out from it in one or both directions. The promenades are lined with wooden summer cottages facing the river. We have several criticisms regarding the validity of this planning type, specifically where the intrusion into the natural landscape is concerned. There is the issue of untreated sewage spilling into the Katun, all the more urgent as all the facilities that we have discovered are located within the boundaries of a specially protected natural area.

It is quite evident that, with its current urban development experience, the Altai region has arrived at a point where a new model is necessary: an architectural and urban planning layout model for waterfront landscapes in the Altai Mountains region, including new recreation hubs (Morozova, 2012).

Having analyzed the current methodological approaches to territorial planning, we have opted for Walter Christaller's central place theory (Christaller, 1933), along with the methodological tools for urban development prediction, designed by A. V. Ryabushin (Ryabushin, 1983), and RAS member V. V. Vladimirov (Vladimirov, 1996) and Professor A. G. Bolshakov's (Bolshakov, 2003) eco method. By combining these approaches and applying them to the target territory, we managed to single out several segments that have not been explored yet but may potentially be transformed into recreation hubs:

– the left and right bank of Uznezya, a river that flows into the Katun from the east,

– the point where the Kuyum stream flows into the Katun (near the intersection with the Chemal Highway),

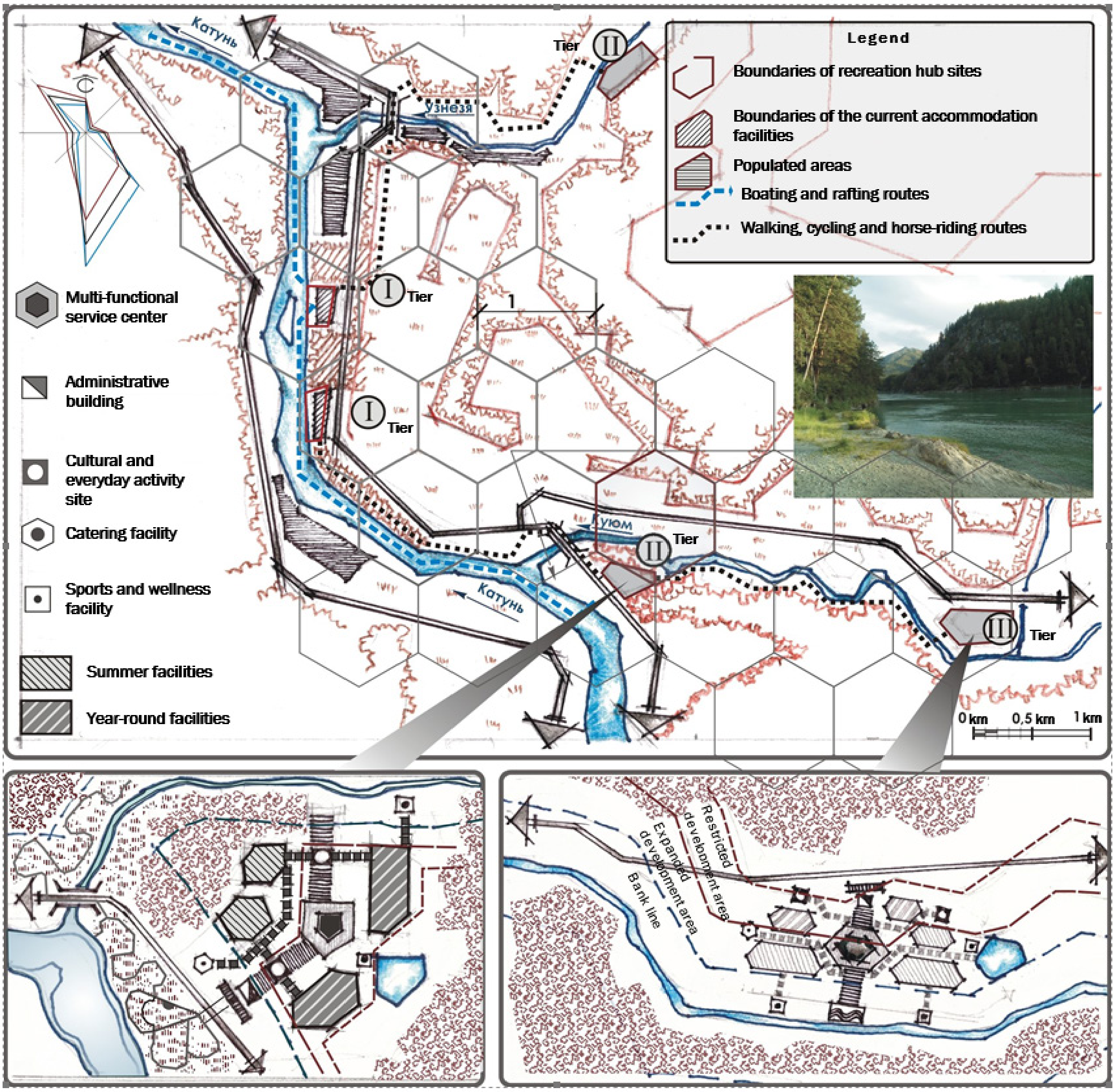

Figure 3. Architectural and urban planning layout model

– along the Verkhny Cheposh stream,
– in the direction of the Ust-Sema river (where a new bridge has been completed, in addition to the old river crossing).

These points are compliant with all the objective factors that impact the choice of recreation hub location (natural/transportation axis crossing). Our next step was to apply a layout grid, in increments of 1 km (10–12-minute walk). We managed to determine the optimal distance between the current dense recreational development areas (Korogon tourist complex, Svoya Usadba camping center), which we shall be referring to as the first service tier, and the potential sites for new recreation facilities, or the second and third service tiers.

That said, the officially approved territorial planning documents do not provide for new recreational service facilities, which is highly concerning, as it might be possible that the unique natural terrain and valuable ecosystems will continue to suffer from haphazard development. Therefore, it is vital to impose boundaries along the Katun bank line and ease the load by redirecting recreational development deeper inland, in relation to the main planning axis. A number of Soviet urban development experts suggested forming a recreational service facility network for resorts in the Baltic (V. P. Stauskas) or along the shore of Lake Baikal (Yu. B. Khromov); they considered this the most appropriate way of preserving fragile waterfront ecosystems. We shall build upon these ideas in the unique context of the Altai Mountain region, offering our own landscape and urban planning solution for the target territory. During the first planning stage—so that the development along the Katun does not merge into an uninterrupted line—we suggest splitting the development into localized sections with buffer zones in between. Such buffer zones are easy to create by planting trees (forest belts). Then we suggest prohibiting further construction along the Katun bank and instead designating development sites that would be perpendicular to the river, along smaller mountain rivers and streams (Uznezya, Kuyum, and Cheposh) that flow into the Katun. Our plan involves creating a distance of at least 100 meters between the development area and the small river bank, as recommended by Professor A. G. Bolshakov (Bolshakov, 2003), as well as positioning several small groups of recreation facilities perpendicular to the natural axis (river) rather than in parallel. Utilities are an area of special focus: sewage must not enter the water. Instead, it can be stored in underground vats until a residue condenses, and then removed by special transport.

We present our model of an urban planning layout for waterfront areas (Fig. 3).

The model is based on the principles of eco-oriented land use, developed by a number of researchers: Von Haaren (Von Haaren et al., 2008), McHarg (McHarg, 1969), Craig W. Johnson (Johnson and Buffer, 2008), Balkenhol (Balkenhol et al., 2016). This model implies creating parallel strips along the water edge (Skryabin, 2013). The waterfront is to be followed by an expanded development zone, where it is allowed to build year-round structure groups; after that, it is suggested creating a restricted development zone with small-capacity, summer-only facilities. On the layout axis perpendicular to the bank, we could place a multi-functional service center, with pedestrian links to sports and wellness facilities and catering facilities. As the mountain river is cold and poorly suited for bathing, it would be reasonable to create a shallow artificial pool within the recreation hub (Morozova, 2012).

An important feature of the recreation hubs within our model is their tier-based arrangement (Skryabin, 2013). The first-tier hubs will combine static year-round facilities and a row of seasonal cottages and small vacation homes. The second-tier hubs will feature portable structures that will facilitate the temporary expansion of short-term accommodation facilities. The third-tier hubs will include summer housing and portable accommodation.

Each hub will have its own designated zone of influence, where guests can walk and relax. We suggest making the size of this zone proportionate to the walking distance: 0.5 km (200 ha) for the first tier, and 1 km (60 ha) for the second and third tiers. The capacity norm for the hubs themselves must be compliant with the recommended recreation load (Pavlova, 2015): 7 people per hectare. In this case, there should be no more than 140 tourists vacationing in the first tier. The second- and third-tier recreation hubs, when located in the center of their zone of influence, will have a capacity of 420 people. The larger capacity of the second- and third-tier hubs will allow for redistributing the influx of tourists, i.e. leading it away from the environmentally vulnerable banks of the Katun towards the inland slopes of the Altai mountains, which are more resistant to recreational load.

The results of this study were discussed during the 12th International Conference on the modern issues of architecture and construction, hosted by the Saint Petersburg State University of Architecture and Civil Engineering. During a follow-up discussion, we received valid feedback from experts in urban planning theory and practice: Professor A. G. Bolshakov and Professor A. G. Vaytens.

Conclusions

Due to the development overload on the Katun bank, which has unique natural landscapes, we need to redirect the stream of recreational development towards more resistant territories. Such territories, according to Professor Bolshakov's findings, include mountain slopes. Therefore, we believe it most reasonable to continue developing the area deeper

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inland, perpendicular to the Katun bank. Our layout model is based on the rational positioning of new recreational development and aims to reduce the impact of economic and investment activity on the natural terrain.

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МОДЕЛЬ ГРАДОСТРОИТЕЛЬНОЙ ОРГАНИЗАЦИИ ПРИБРЕЖНЫХ РЕКРЕАЦИОННЫХ ЛАНДШАФТОВ ГОРНОГО АЛТАЯ

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Аннотация

За последнюю четверть века вопросы градостроительного развития региональных систем расселения не были приоритетными в широких кругах управленцев и профессионалов, больше внимания уделялось проблемам расширения крупных городов–мегаполисов (Москва, Санкт-Петербург, Екатеринбург, Казань и несколько других, всего семь). Одновременно, градостроительное освоение уникальных природно-ландшафтных территорий в регионах являлось самостийным, малозаметным процессом, оставленным без должного внимания со стороны профессионалов. Были застроены уникальные природные ландшафты побережья Байкала без разработки градостроительной документации, проданы под вырубку леса обширные природные территории Иркутской области, интенсивное развитие не запланированных рекреационных узлов наблюдается в Алтайском Крае и в Республике Алтай. **Цель исследования:** Разработка градостроительной модели планировочной организации уникальных природных территорий. **Методы:** Многофакторной оценки, фотофиксации, метод социологического опроса, метод графического моделирования. **Результаты:** Модель, разработанная авторами, отображающая оптимальное размещение новых рекреационных узлов с точки зрения сохранения уникальных экологических качеств природного ландшафта.

Ключевые слова

Градостроительство, ландшафты, рекреационная среда, экология, устойчивое развитие.

Surface Transportation Engineering Technology

THE RISE OF THE QUANTOMOBILE THEORY

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Abstract

Introduction: The progress of science at the turn of the 21st century has made it possible to create new quantum engines (QEs), powered by physical vacuum energy. The thrust force generated by QEs can be applied to the vehicle's body directly, with no transmission required. This will completely transform the transportation industry: the traditional cars will be upgraded with QEs and thus converted into quantomobiles. Ahead of this major transition, we believe it necessary to outline the quantomobile theory. **Methods:** We formulate and review the key concepts of the quantomobile theory from the systemic, philosophical standpoint, drawing analogies from the existing automobile theory. We also present models of this hypothetical vehicle's components and functions. **Results:** The study results in the following: a structure of the quantomobile theory; an overview of the vehicle's hypothetical configuration, its constructive and operational features, force balance specifics, and movement patterns, along with various aspects of acceleration time, off-road performance, ease of operation, and other features; an analysis of the vehicle's thrust and speed characteristics that are shaped by the QE thrust. The vertical component of the thrust vector is sufficient both for hovering and pressing down the vehicle. This enables both the airborne and underwater quantocraft modes, transforming the quantomobile into an all-purpose, multi-modal vehicle (multi-modal quantomobile, or MMQ). **Discussion:** The quantomobile theory, even on the purely hypothetical level, will be of use at the early stages of designing quantomobiles and their subclasses, conducting R&D, developing infrastructure, and supplying the transportation industry with the equipment and HR required.

Keywords

Quantum engine, quantomobile, force balance, airborne quantocraft, underwater quantocraft, multi-modal quantomobile (MMQ), quantomobile theory.

Introduction

By the early 21st century, breakthroughs in physics and the progress of science and technology had created the necessary prerequisites for the emergence of entirely new propulsion systems: fuel-free quantum engines (QEs). Putting certain theories — such as V.S. Leonov's Superunification Theory (Leonov, 2002, 2010, 2018) — into practice will make it possible to generate energy from the physical vacuum. This new capability will extend to vehicles' power units.

A new generation of vehicles with quantum engines (QEs) — quantomobiles — will replace automobiles. We introduced and rationalized the usage of the "quantomobile" term in a previous study (Kotikov, 2018e).

The principal difference between a QE and an ICE is that the QE will generate a vector-based propulsive force, or thrust, applicable to the vehicle's body directly, with no transmission required (Kotikov, 2018c, 2018d, 2018g, 2019d; Leonov, 2010, 2018). The thrust vector's angle creates a vertical component, suitable for either hovering the vehicle (up to the point when it transforms into an airborne quantocraft) or pressing it down (so it can function as an underwater quantocraft). We have conducted several studies (Kotikov, 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g, 2019a, 2019b, 2019c, 2019d, 2019e, 2019f, 2019g, 2019h, 2020a, 2020b) where we elaborated on several aspects of this subject, with respect to both vehicles and lifting machinery.

The introduction of QEs will revolutionize the entire range of research insights and equipment used in the transportation industry: the traditional cars will be upgraded with QEs and thus converted into quantomobiles. This calls for outlining the quantomobile theory. It will be of use at the early stages of designing quantomobiles and their structural subclasses, conducting R&D, developing infrastructure, and supplying the transportation industry with the equipment and HR required.

The concepts outlined below are based on 16 of our research papers, thus presenting a summary of

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what we have achieved thus far. It bears pointing out that, while our research has received a critical response, we do not yet possess any information as to whether other researchers have published their own works featuring either similar concepts or the quantomobile theory as such.

Creation of the general quantomobile theory structure

Building upon the achievements of the automobile theory over the past century, as well as bearing in mind the discovery, conceptualization, and the need for exploration in the realm of the physical vacuum, we deem it useful to go over the following aspects of the quantomobile theory:

1. Subject matter of the quantomobile theory.
2. Concepts of the Superunification Theory and their application in transport.
3. Conceptual foundation of quantum engines.
4. Quantomobile structural design.
5. Quantomobile thrust and speed characteristics.
6. Quantomobile braking dynamics.
7. Quantomobile aerodynamics.
8. Ease of operation.
9. Stability.
10. Off-road performance.
11. Maneuverability.
12. Energy efficiency.
13. Safety.
14. Infrastructure and maintenance features.

We have already laid down the conceptual foundations for the above, in varying degrees of detail. The first five items on the list above have been covered more extensively. We have published a number of papers on the subject (Kotikov, 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g, 2019a, 2019b, 2019c, 2019d, 2019e, 2019f, 2019g, 2019h, 2020a, 2020b). The other items have been touched upon briefly, as essential elements of our theory's structure.

1. Subject matter of the quantomobile theory. The term "quantomobile" was first introduced in our study (Kotikov, 2018e). This term denotes a self-propelled vehicle and/or lifting machine that is powered by a quantum engine and can be used for moving cargo, passengers, special equipment, and other objects.

The *quantomobile theory* is a discipline that studies the mechanics of the quantomobile, the way it interacts with its main support surface (ground) and additional surfaces (air and water), and its structural and operational parameters.

The theory studies the innovative vehicle that is supported by wheels, sleds, or other structural elements suitable for overground movement, and is also capable of hovering above ground (in the airborne quantocraft mode) or pressing down and converting into an underwater quantocraft (quantomarine). Vehicles of this type can be described as multi-modal vehicles (MMVs) (Military.com, 2013; Zhu, 2009). In our case, the MMV is a multi-modal quantomobile (MMQ).

The subject matter of the quantomobile theory is a set of principles that describe the mechanics of MMQ's movement, as well as its interaction with the ground, air, and water, and operational properties.

The goal of the quantomobile theory is to provide a mathematical description and simulate the motion mechanics of the MMQ as a complex system, as well as demonstrate how the vehicle's mechanisms and systems function and shape its operational properties.

Just like the quantomobile has inherited a variety of properties from the traditional automobile, so has the quantomobile theory borrowed a certain set of concepts from the traditional automobile theory. Being an MMQ, the quantomobile also takes certain properties from aircraft, waterborne vessels, and submarines, and can be described with relevant terms and concepts.

2. Concepts of the Superunification Theory and their practical application. The Superunification Theory (Leonov, 2010) considers the process of space-time quantization. This process involves filling space with quantons. A quanton consists of four quarks: two electric and two magnetic, which form a tetrahedron with two orthogonal dipoles. Those two dipoles form an electromagnetic quanton quadrupole. The four quarks making up a quanton combine electricity and magnetism in the form of a unified electromagnetic substance, the carrier of which is the four-dimensional quantized space-time (QST). The physical vacuum in the universe is filled with moving quantons, likened to a "boiling broth". The interaction between the quantons depends on their proximity, the charge sign of the adjacent quarks in neighboring quantons, and the orientation of dipole axes (Kotikov, 2018g; Leonov, 2010).

The equilibrium state of a QST fragment implies that the resultant vectors of axial forces of dipoles equal zero in any direction. The "intrusion" of free quarks into a fragment perturbs the electromagnetic field, bending it relative to the initial equilibrium state (in this case the resultant force zero vector acquires magnitude and direction). By controlling the introduction of free quark sets, we can manipulate changes in the vector (Leonov, 2010).

According to the results of experimental studies conducted by V. S. Leonov, external fields can interact with the QST structure, resulting in stable anti-gravity effects. We can consider the outer space as an elastic super energy-dense medium having an electromagnetic structure with overall support and sufficient energy. We should learn how to interact with the medium and manage this interaction (Leonov, 2002, 2010).

3. Conceptual foundation of quantum engines. The rotation of the electromagnetic quadrupole generates the Lorentz force, which, in turn, creates the axial thrust. During the process, the quadrupole "drills" into the surrounding medium and thus moves forward, not unlike a propeller (Leonov, 2002, 2010, 2018).

If the quanton is forced to rotate, this generates the field thrust, causing it to move through space. The physics of the process is based on the interaction of fields (the rotating field of the quadrupole and the sign-alternating field of the quantized medium). In other words, QEs are engines where the thrust is caused by field interaction.

To create thrust without the ejection of reactive mass, it is necessary to switch over to the open quantum-mechanical systems, treating QST as an elastic quantized medium. Consequently, it is possible "to push away" from such an elastic quantized medium, thus generating thrust. This does not contradict Newton's third law. As per the Superunification Theory, a QE is an open quantum-mechanical system — as opposed to an internal combustion engine (ICE), which constitutes a closed thermodynamic system (Leonov, 2010, 2018).

4. Quantomobile structural design. Fig. 1 presents a layout of a quantomobile with two QEs (Leonov, 2010). A single QE unit has the capacity for combining a vertical and horizontal thrust and adjusting the thrust direction. It will also be possible to install several QEs in a single vehicle, each with its own purpose (such as ensuring buoyancy, generating a horizontal thrust, creating a maneuvering impulse, etc.)

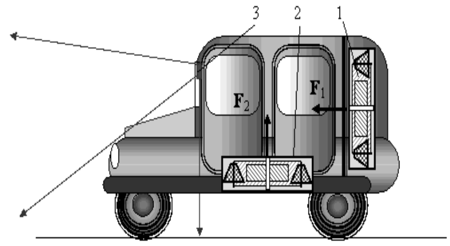

Figure 1. Off-road vehicle with an anti-gravity cushion, powered by two QEs: 1 — a QE with a horizontal thrust F_1; 2 — a QE with a vertical thrust F_2; 3 — a scanning radar (Leonov, 2010).

5. Quantomobile thrust and speed characteristics (TSC). TSC are the key features of the quantomobile, and describing and rationalizing them is a top priority, tied to the fundamental goal of researching the vehicle's capacity for being propelled by QE thrust. We believe that the following aspects of TSC analysis must be considered first:

5.1. Energy flow direction and the creation of the vehicle's force balance. We review the conceptual basics of these aspects in (Kotikov, 2018c, 2018d, 2018g, 2019e).

5.2. Features of the quantomobile's power unit. This aspect is represented in (Kotikov, 2018c, 2018d, 2018g, 2019c, 2019e, 2019f).

5.3. Quantomobile modes. In (Kotikov, 2019a), we study the vehicle's overland modes, as well as its capacity for hovering if the vertical thrust component is prominent enough. In this paper, we are going to provide a more in-depth list of MMQ modes, including waterborne and underwater modes (Table 1). Note that G_q is the quantomobile's weight.

Table 1. Multi-modal quantomobile (MMQ) operation modes

No.	Operation mode	Environment	*Vertical component of the thrust* F_{Tz}	Typical features
1	Longitudinal vertical motion	air	$F_{Tz} > G_q$	Vertical breakoff possible
2	Longitudinal boundary motion, full hovering	air	$F_{Tz} = G_q$	Horizontal motion above ground
3	Longitudinal motion, partial hovering	Air-ground	$0 < F_{Tz} < G_q$	Thrust vector optimization possible
4	Longitudinal motion, no hovering	Air-ground	$F_{Tz} = 0$	Traditional automobile mode
5	Longitudinal motion along the shallows (up to the floor)	Air-ground-water	$F_{Tz} = 0$	Road resistance increases substantially
6	From the floor to the water line	Air-ground-water	$F_{Tz} = 0$	Resistance shifts from ground to water
7	Floating above the water line	Air-water	$F_{Tz} = 0$	Boat / motor boat mode
8	Submerged from the water line to the roof	Air-water	$F_{Tz} < 0$	The thrust presses the vehicle down, converting it into a submarine
9	Submerged from the roof to 0.5 L_{body}	Water	$F_{Tz} < 0$	Underwater quantocraft (quantomarine) mode, with intensive wave formation
10	Submerged deeper than 0.5 L_{body}	Water	$F_{Tz} < 0$	Underwater quantocraft (quantomarine) mode, no waves

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5.4. Course control. The key idea is to vary the magnitude and direction of the thrust vector in the MMQ pitch plane (Kotikov, 2019a, 2019c, etc.). See Fig. 2.

If it is technically possible to retain the β angle of the thrust vector $\boldsymbol{F_T}$ in the longitudinal vertical plane, then the vector can be split into two components, $\boldsymbol{F_{Tx}}$ and $\boldsymbol{F_{Tz}}$. Then, the first and second quadrants of its coverage area will experience hovering, with an upward force $\boldsymbol{F_{Tz}}$; while the third and fourth quadrants will experience pressing-down by a downward force $\boldsymbol{F_{Tz}}$.

The vehicle hovers in modes 1–3 of the MMQ (Table 1). Modes 8–10 of the MMQ are characterized by the vertical component of the thrust vector that presses the vehicle down.

As the vehicle's buoyancy reduces road resistance and helps it hover but also requires high levels of power consumption, the movement trajectories need to be optimized.

5.5. Quantomobile acceleration time: this aspect depends on the MMQ force balance and the reserves of thrust that remain after ensuring that the quantomobile moves smoothly. It is possible to produce MMQs with different acceleration capacity, but the maximum acceleration will be restricted by biomechanical limits. We should note that, aside from the traditional horizontal acceleration, vertical acceleration should also be taken into account.

5.6. Quantomobile hovering in the quantocraft mode. This is operation mode 1 (Table 1). The requirements for this mode are: ensuring good aerodynamics and keeping the carrying wheels inside the vehicle's outline.

5.7. Modes 6 and 7 are waterborne modes. In these modes, the vehicle's floor must be sustained by good hydrodynamics along the water line, and the presence/absence of carrying wheels must be optimized.

5.8. Pressing down and transforming the quantomobile in a quantomarine. This corresponds to modes 8–10. The requirements for this mode are: ensuring good hydrodynamics and keeping the

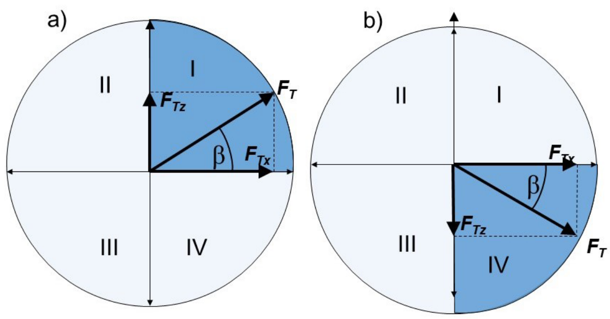

Figure 2. Circular diagram of the possible thrust vector $\boldsymbol{F_T}$ directions: a) hovering vehicle variation; b) pressed-down vehicle variation

carrying wheels inside the vehicle's outline. Aside from the F_{Tz} value, an important aspect of controlling the vertical component of the MMQ trajectory is the adjustment of the vehicle's trim. It is vital to remember that, when a vehicle is submerged to an equivalent of half its body length or more, resistance decreases substantially, as there is no more wave formation (Wikipedia, 2017).

5.9. Energy flow direction and the creation of the vehicle's force balance.

As we transition from the automobile to the quantomobile, it would be useful to compare the generation of the respective thrust forces: P_T (automobile) and F_T (quantomobile). See Fig. 3. A quantomobile has no transmission, driving wheels, or suspension elements responsible for shifting the thrust force. This simplifies its structural layout (Kotikov, 2018c, 2018d, 2018g).

Fig. 4 provides the full thrust balance picture (Kotikov, 2018c, 2018d, 2018g). The area of the automobile's thrust forces is highlighted in yellow. The area highlighted in blue (ranging from dark to light) shows the quantomobile thrust values F_T. We can see that the vehicle possesses excellent force and power capacity. The different shades of the highlights roughly correspond to the QE force capacity; note that the limits for the regulatory characteristics are scalable from 1 to 4.

5.10 Quantomobile force balance equation

Buoyancy is ensured by the capacity for rotating the thrust vector F_T within the pitch plane. In (Kotikov, 2019a) we show that it is fundamentally incorrect to represent the thrust F_T as an arithmetic sum of scalar values representing the horizontal thrust F_{Tx} and the vertical thrust F_{Tz}. Therefore, quantomobile balance differs from that of a traditional car. According to (Kotikov, 2019a), the quantomobile force balance equation is as follows:

$$
\begin{aligned}
&F_T^2 = F_{Tx}^2 + F_{Tz}^2 = \left(P_f + P_{w.x} + P_{j.x}\right)^2 + \\
&+ \left(P_{w.z} + P_{j.z} + P_g\right)^2 = \Bigg(f_{к0}\,(1 + f_{кV} \cdot V_x^2) \cdot \\
&\cdot (G_q - F_{Tz}) \Big| F_{Tz} \le G_q + k_{w.x} \cdot S_{front} \cdot V_x^2 + \frac{G_q}{g} a_x \cdot \\
&\cdot\ (1 + \delta_w) \Bigg)^2 + \Bigg((k_{w.z} \cdot S_{plan} \cdot V_z^2 + \frac{G_q}{g} a_z) \Big| F_{Tz} > \\
&> G_q + \min(F_{Tz}, G_q) \Bigg)^2 ,
\end{aligned}
\qquad (1)
$$

where F_T, F_{Tx}, F_{Tz} is the thrust and its respective coordinate components, N; P_f is the resistance against the rolling of wheels, N; $P_{w.x}$ is the wind resistance against horizontal motion, N; $P_{j.x}$ is the resistance against horizontal acceleration, N; $P_{w.z}$ is the wind resistance against vertical motion, N; $P_{j.z}$ is the resistance against vertical acceleration, N; P_g = min (F_{Tz}, G_q) is the part of the thrust's vertical component that neutralizes the hovering vehicle's γ share of the gravity force (γ = F_{Tz} / G_q), N; f_{w0} is

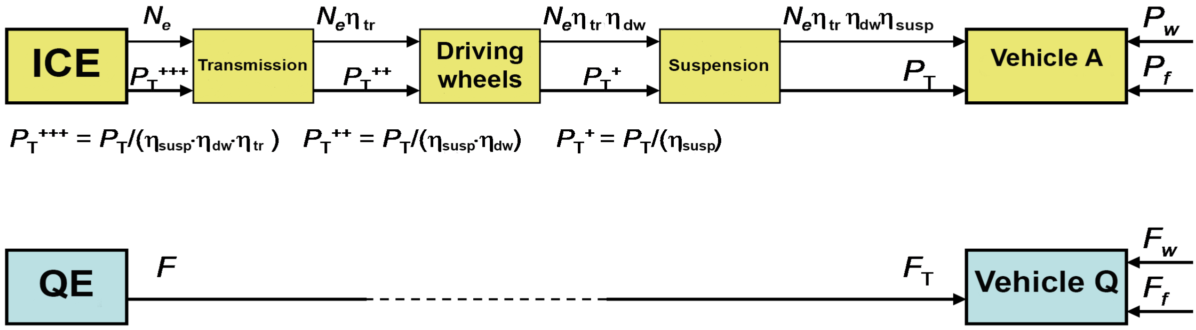

Figure 3. Comparison of thrust force generation in an automobile (P_T) and quantomobile (F_T)

the resistance coefficient for driven wheels when the speed approaches zero and F_{Tz} = 0; f_{wV} is the speed coefficient of resistance against the rolling of driven wheels, s²/m²; V_x is the current speed of the vehicle's longitudinal movement, m/s; G_q is the quantomobile's weight, N; $k_{w.x}$ is the vehicle's horizontal wind shape coefficient, N×s²/m⁴ ; S_{front} is the vehicle's frontal area, m²; g is gravity acceleration, m/s²; a_x is the vehicle's longitudinal acceleration, m/s²; δ_w is the inertia coefficient for rolling wheels; $k_{w.z}$ is the vehicle's vertical wind shape coefficient, N×s²/m⁴; S_{plan} is the vehicle's size in plan view, m²; V_z is the vehicle's vertical speed, m/s; a_z is the vehicle's vertical acceleration, m/s²; $|F_{Tz} \le G_q$ is the permissible value range for F_{Tz} in the pressing-down or partial hovering mode (without the vehicle being lifted off the ground); $|F_{Tz} > G_q$ is the permissible value range for F_{Tz} in the full hovering mode.

If we apply equation (1) to waterborne and underwater modes 6–10, the last member of the equation, min(F_{Tz}, G_q) must be replaced with the following: (F_{press} – G_q), which represents the submerging force F_{sub} (Wikipedia, 2017).

6. Quantomobile braking dynamics. While

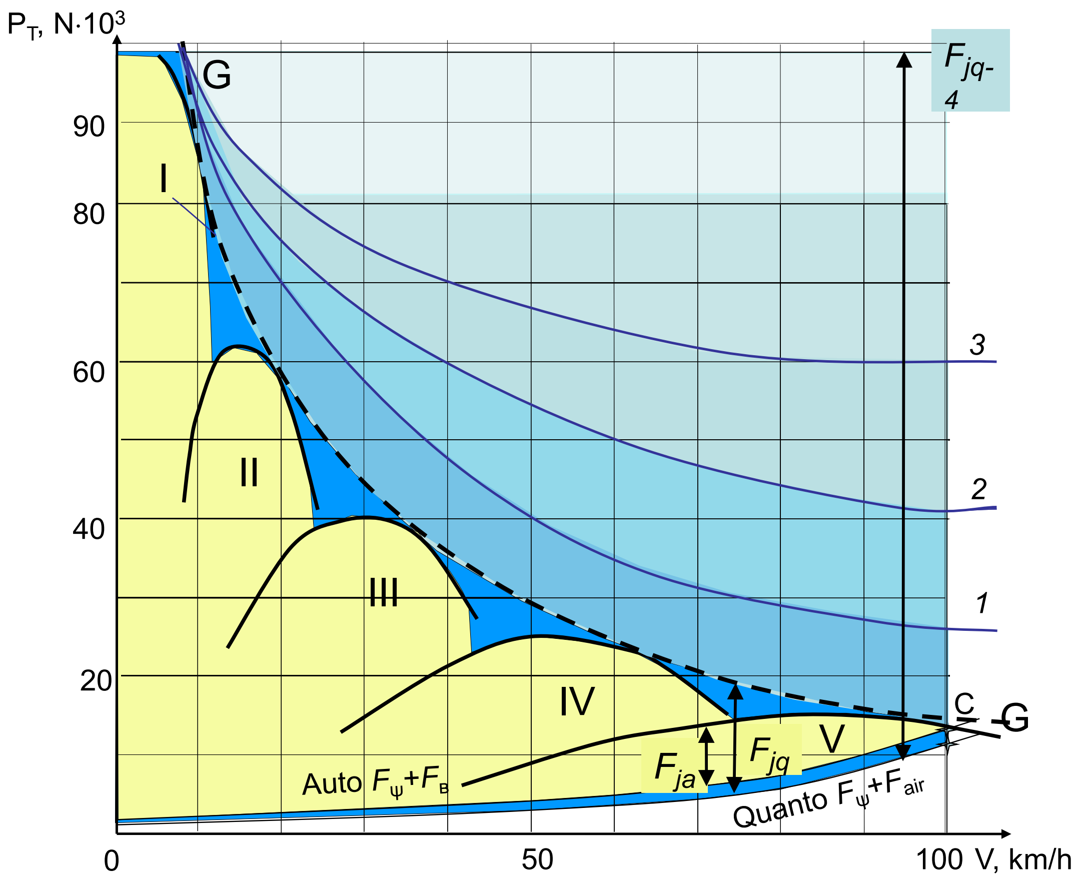

Figure 4. Thrust balance of an automobile (yellow) and quantomobile (blue): GG — a hyperbola enveloping the automobile's thrust force diagrams; I…V — the transmission speeds; 1…4 curves — the possible ways in which the QE can exhibit its limit regulatory characteristics

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quadrants I and IV (Fig. 2) are meant to reflect the vehicle's uniform and accelerated translational motion overland or through the air, quadrants II and III show the vehicle's slowing down and braking processes, as seen from the QE, with the backward rotation of the thrust vector. A combination of the horizontal ($\boldsymbol{F}_{Tx}$) and vertical ($\boldsymbol{F}_{Tz}$) thrust components might also facilitate smoother braking.

The emergency braking system will be more effective: a vertical force vector will put pressure on wheels to maintain roadholding during corner braking, with optimal weight distribution. The complex downhill assist systems (ABS, etc.) will become obsolete. All a quantomobile needs is rotating the thrust backward and regulating its magnitude (Kotikov, 2018b, 2018f).

7. Quantomobile aerodynamics. A quantomobile has no drive shafts or drive housings, thus making room for a clad floor and reducing air and water resistance.

The specific features of the vehicle's body, floor, and tail (both for air and for water) require further study.

8. Ease of operation. Lateral motion control. There is a need for assessing this feature's efficacy, in tandem with course control, ease of operation, off-road performance, and maneuverability.

The introduction of a jointed QE unit enables wheel steering, which adds to ease of operation. Lateral motion and maneuvering (changing the vehicle's position in relation to the pitch plane), both through water and through air, will become possible thanks to the lateral thrust component.

If the quantomobile supports a joint-based QE or alternatively, if the thrust vector outlines the entire three-dimensional space (i.e. that the thrust has a lateral component), this will create a centripetal force that will counter the centrifugal force along the raised curve. This is useful for high-speed motorways. The rigid angle of the path (adopted for a certain speed level) may be replaced with a flexible transverse thrust component, easily adjustable depending on the vehicle's speed.

9. Stability. If the friction is insufficient, the vertical vector may press down on the wheels. Quantomobiles should be able to move over steep hills. A "rigid" thrust will be able to significantly stabilize the vehicle in the waterborne mode, even if the waves are strong.

10. Off-road performance. Good off-road performance is ensured by a clad floor. The quantomobile is capable of traveling uphill at a steep angle, without having to rely on high-speed dynamics. Hovering will also contribute to improving performance in extremely poor off-road conditions.

11. Maneuverability. Wheels turn around the vertical axis more easily and simultaneously on all axles. Quantomobiles can still require an independent drive for wheels, to facilitate maneuvering.

12. Energy efficiency. The QE allows the vehicle to set off with consistent thrust. This will make it possible to use its power capacity to the max, avoiding the losses typical of internal combustion engines. Energy is recovered during cyclic movement.

13. Safety. Noise level: the wheels make less noise in the driving mode. No power drive elements means no vibration. The means of cooling the QE are yet to be determined. The heat impact on the vehicle and the need for heat protection merit further study. This vehicle will produce fewer chemical emissions. At this point, it is hard to predict the impact of high-frequency QE fluctuations.

14. Infrastructure and maintenance features. The vehicle will not need refueling on a regular basis. The entire system of vehicle maintenance will change. Changes in roads and traffic regulations will be observed as well.

Conclusion

We have now summarized the structure of the multi-modal off-road quantomobile, or MMQ, theory. Most of the concepts and sections are the legacy of the automobile theory concepts. Even though the theory so far remains hypothetical, its structure still could (and should) receive more functional additions. It also requires conceptual additions from aircraft building, rocket science, and submarine theory.

As we gather more materials on how this innovative vehicle may be used in practice, the demand for the quantomobile theory will grow.

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ВОЗНИКНОВЕНИЕ ТЕОРИИ КВАНТОМОБИЛЯ

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Аннотация

Продвижение научно-технической мысли к началу 21 века обозначило возможность создания квантовых двигателей (КвД), использующих энергию физического вакуума. КвД генерирует тяговую силу (траст), которую можно непосредственно, исключая трансмиссию, прикладывать к корпусу транспортного средства (ТС). Эта особенность приведёт к перевооружению транспортной отрасли – классический автомобиль при установке на нем КвД трансформируется в квантомобиль. В преддверии этого преобразования появляется необходимость формирования теории квантомобиля. **Методы:** С системных позиций, на базе философского осмысления, с привлечением аналогий по теории автомобиля, моделирования компонент и активностей гипотетического ТС сформированы и рассмотрены основные концепции теории квантомобиля. **Результаты:** Построена структура теории квантомобиля. Рассмотрена возможная конфигурация этого ТС, его конструктивные и эксплуатационные свойства, особенности силового баланса, варианты движения, аспекты приемистости, проходимости, управляемости, других свойств. Подвергнуты анализу тягово-скоростные свойства ТС, формируемые под действием трас та КвД. Вертикальная компонента вектора траста может обеспечить как вывешивание, так и поддавливание экипажа, что позволит реализовать как режим квантолета, так и режим квантомарины, и таким образом сформировать всесредный мультимодальный квантомобиль (Multi-modal quantomobile (MMQ)). **Обсуждение:** Теория квантомобиля, даже на гипотетическом уровне, будет небесполезной при раннем формировании типажа квантомобилей, их подклассов, совокупности НИОКР, развития инфраструктуры, технической и кадровой подготовки транспортной отрасли.

Ключевые слова

Квантовый двигатель, квантомобиль, силовой баланс, квантолёт, квантомарина, мультимодальный квантомобиль (ММК), теория квантомобиля.