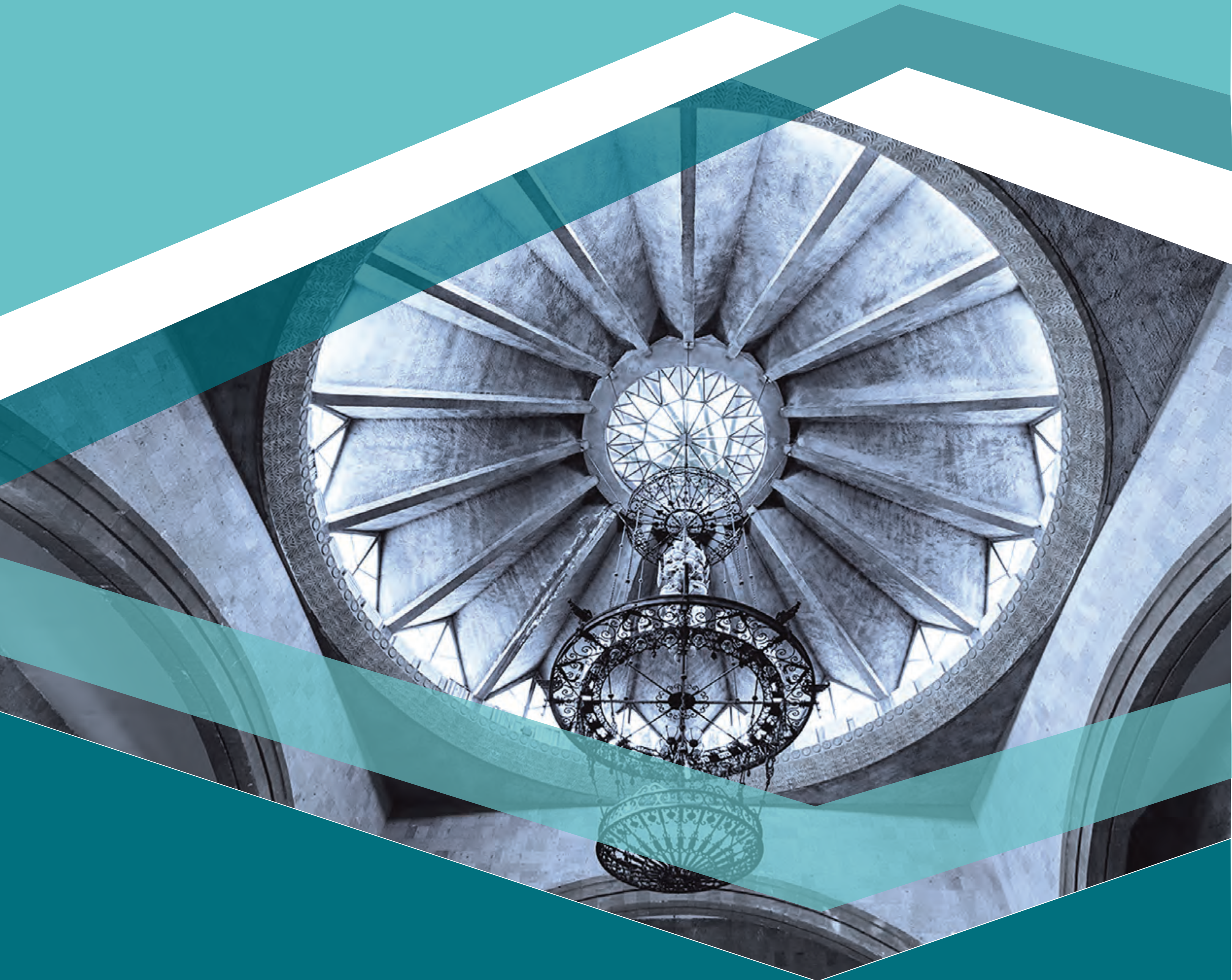
ISSN 2738-2656

2024-7



JOURNAL OF ARCHITECTURAL AND ENGINEERING RESEARCH

National University of Architecture and Constraction of Armenia approve the journal for publication
Scientific Council

THE MINISTRY OF EDUCATION, SCIENCE, CULTURE AND SPORTS OF THE REPUBLIC OF ARMENIA

JOURNAL OF ARCHITECTURAL AND ENGINEERING RESEARCH

2 0 2 4 - 7

YEREVAN 2024

CONTENT

CONSERVATION PROBLEMS OF WALL PAINTINGS WITHIN THE ARCHITECTURAL HERITAGE

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Abstract: *The Armenian legislation is currently protecting and preserving architectural monuments, archaeological sites, and minors' artistic forms of art like xač'k'ars. Unfortunately, there are several cases of precious wall paintings preserved inside religious buildings (Tat'ev, Lmbatavank', K'obayr, Mastarà) being damaged during architectural monument restoration. In recent years, there has been a lot of interest in study, conservation, and restoration of wall paintings in Armenian churches; however, there is one terrible reality to report: the neglect and abandonment of the protection and safeguarding of visible wall paintings for many bureaucratic and logistical reasons, as well as reasons for complete indifference for the destiny of the frescoes. A significant illustration of this negative attitude is the chapel of the Armenian monastery of K'obayr. After many years of abandonment, the Armenian Ministry of Education, Science, Culture and Sport made a move and began a campaign of studies and restorations in collaboration with the Polytechnic of Milan, to restore the buildings and wall paintings. Restoration work on the K'obayr chapel has been put on hold since 2013 due to inadequate administrative administration. As a result, the chapel's single nave's double-pitched roof, which is incomplete has remained exposed for the past 10 years, and rainwater infiltration formed a lovely part of the wall paintings. Our four years of endless reports and reminders have yielded nothing. The purpose of this article is to show once again, that the wall paintings in Armenian churches are historical monuments that must be safeguarded and are an inseparable key component of each existing church's monumental architectural heritage; consequently, they must be protected.*

Keywords: *K'obayr, Mastarà, Lmbatavank', Axt'alà, Karmravor, Art'ik..*

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Received: 10.06.2024
Revised: 02.07.2024
Accepted: 15.07.2024

Introduction

There are limited references in Armenian architecture studies to wall paintings preserved in churches and templets that were created immediately after the church was built or later. Architecture and wall painting art are inseparable values, and one compliments to the other [1-3]. The Armenian church is a volumetric and geometrically secluded and mysterious environment created by a masterful combination of stone constructions. The wall paintings that survived on the internal walls, were made by using lime, sand, and mineral pigments to convey the ideas and commandments of spiritual values. The union of these two beautiful forms of cultural expression gives power and meaning to the spiritual structure, making it the cradle of Christianity's conservation and spread. The prevalence of wall paintings in churches, their depictions, painting skills, and color solutions reveal an important yet unexplored part of Armenian culture. According to our research, there were at least three regions in Armenia with wall-painted churches: the northern area, bordering Georgia (Kiranc', Khučap, K'obayr, Hałbat, 10-13th century); the central area - on the slopes of Mount Aragac (Lmbatavank', Art'ik, Mastarà, Koš, T'alin, Aruč, 7th century); and the southern area - bordering Iran (Surb Hovhannes, Surb Astvacacin, Surb Sargis, all in Mełrì, 17-18th century). A preliminary study of the wall paintings preserved in the churches of these three regions revealed their differences as well as their exceptionally high artistic value. In the Armenian highlands, many churches have been built and painted since the early days of Christianity. Many wall-painted churches in Ani's capital require a separate investigation

(Tigran Honenc‘, Sant Savior, and the Cathedral). The study of the numerous fragments of wall paintings that survived to this day, both from the early Christian and mature Middle Ages, is possible only because they have been preserved and restored.

The historian Vrtanes Kertogh in his treatise «Յաղագս պատկերամարտից» (About Iconoclasts) [4,5], written in the 7th century, exhaustively illustrates the presence of wall paintings in numerous churches of the time and the use of natural mineral pigments as well as pigments of vegetable and animal origin in the design they created. There is inadequate knowledge of the subject because of a lack of studies due to the large number of abandoned historical monuments on Armenian territory. On the one hand, the almost complete indifference of Soviet scholars in an atheist country, particularly for reasons of inappropriate illegal usage of monuments such as kolkhoz grain warehouses, has promoted the degradation and definitive loss of many pictorial fragments preserved in various churches in the territory of the Republic of Armenia. All wall paintings in Armenian churches are little studied for a variety of objective and subjective reasons: wall paintings are erroneously considered to have no local origins, and frescoes are painted by foreign artisans (Byzantines, Syriacs, Georgians, and Franks). We are convinced that painting and architecture are one and single, indivisible thought and that the design of the church and its interior decoration highlight full and harmonious work. There is presently no census and no complete catalog collecting all of Armenia's pictorial heritage [6]. Without this, it is impossible to study, conserve, restore, and produce a catalog of wall paintings in Armenian churches. The fundamental issue is insufficient attention from the government, religious institutions and local population. There is an absence of valorization and appreciation to recognize the value of this great cultural heritage. The lack of knowledge of those people who make decisions is also a major issue. I would like to present our testimony through examples of what happened to us while we were on our mission in Armenia from 2012 to 2022.

Materials and Methods

Our research and work have led to unbelievable outcomes that are evident with the naked eye. As previously stated, the products used for cleaning, phasing, grouting, consolidation, mortar restoration, and wall painting were chosen as the classics utilized in Italy because they were all restored with the consent of the authorities that protect the monumental and visual heritage so well-renowned around the world. The methodology for restoration was developed by the School of Restoration in Italy and is used in Veneto. The decades of professional expertise and the results produced in Venetian churches and palaces show the accurate use of conservative restoration methods used on numerous medieval murals executed in Italy and applied to wall paintings in Armenian churches.

Literature review

We have published numerous articles and four books on wall paintings in Armenian churches:

- Dadivank Revived Miracle.
  Authors: Karen Matevosyan, Avet Avetisyan, Arà Zarian, Christine Lamoureux, Armenian, Russian and English book (with Blessing of Primate of the Artsakh Diosece of the Armenian Apostolic Church Archibishop Pargev Martirosyan), Victoria Foundation, Yerevan, 2018, ISBN 978-9939-1-0690-8.
- The Restoration of the Wall Painting in Several Armenian Churches of First Christian Ages.
  Authors: Arà Zarian, Christine Lamoureux, Armenian and English book (presentation of Patrick Donabédian also in French and Italian), Tigran Metz, Yerevan, 2018, ISBN 978-99941-0-945-6.
- Haghbat- Restauro Conservativo Dei Dipinti Murali Del Secolo X, X-Xiii Nella Chiesa Del Santo Segno, 976-991.
  Authors: Christine Lamoureux, Arà Zarian, Armenian and Italian book (presentation of Seyranoush Manoukian), Tigran Metz, Yerevan, 2019, ISBN 978-99941-0-981-4.

- Dadivanh – La Conservation-Restauration Des Peintures Murals Datées 1297 Dans L’église Kathoghike Construite En 1214.
  Authors: Arà Zarian, Christine Lamoureux, Armenian and French book (presentation of Antonia Arslan), Tigran Metz, Yerevan, 2020, ISBN 978-99941-0-945-6.

Armenia's current legislature protects and preserves architectural monuments, archaeological sites, and small forms of decorative art, such as *xačʻkʻars* [1]. Unfortunately, there are several examples of magnificent frescoes kept inside religious structures that have been substantially lost during the process of restoring architectural monuments (Tatʻev, Fig.1, Lmbatavankʻ, Fig.2, Kʻobayr, Fig.3, Mastarà, Fig.4). Despite recent interest in the conservation and restoration of wall paintings in Armenian churches, there is a negative reality to highlight that leads to the abandonment and neglect of the protection and safeguarding of traces of wall paintings and frescoes for various bureaucratic and logistical reasons. A significant illustration of this negative attitude is the chapel of the Armenian monastery of Kʻobayr, which, after many years of abandonment, when Georgian academics took action to define the monument of Georgian culture (because of the existence of several inscriptions also in Georgian), Armenia's Ministry of Education, Science, Culture and Sport has acted to launch a campaign of studies and restorations in collaboration with the Polytechnic of Milan to restore the building and wall paintings [7]. The work on restoration of the Kʻobayr chapel has been halted since 2013 because of administrative inefficiency. As a result, the incomplete double-pitched roof (1.25 m^2 of slabs missing and the tip of the pitch is 7 ml) of the chapel with a single nave has remained exposed for the last 10 years, and rainfall infiltration has greatly increased the number of wall paintings (Fig.5). Our frequent reports and numerous reminders, which have lasted four years, have led to nothing, and the precious wall paintings are being lost daily. In 2022, we presented an elaborate detailed project (also available in English) to the international scientific commission specializing in the sector of monumental art of the Ministry of Education, Science, Culture, and Sports of the Republic of Armenia for the cleaning, consolidation, and conservative restoration cycle of wall paintings in the chapel of the Kʻobayr Monastery (88 pages, with photos, drawings, analyses, and so on) (Fig.6). The Commission provided some observations and suggestions for project improvements, which we considered. In 2023, we sent the completed project with all relevant components to the Ministry in Yerevan, requesting a date for the new presentation. This response was unexpected. The communication pointed out that the double-pitch roof, which had been left unfinished for 10 years, needed to be finished first. The Commission-approved roof design was now out of date and needed updating by a professional architect (Fig.7). My application was rejected because my authorization license was considered expired. I am the author of approximately 25 restoration projects of religious buildings in Armenia, including Vorotnavankʻ Monastery, Makʻenyacʻ vank’ Monastery, churches in Makaravankʻ, Dapnocʻ vankʻ, Hacʻarat, Solak Mayravankʻ, Kotʻavankʻ, Teł, and others. In 10 years, only a small part of the roof could be completed, and we now must wait another few years for them to find a designer and funding. Our proposal to design and fund the works was rejected. Due to water infiltration and the negligence of the owner, 50% of the wall paintings have been lost.

The competent authorities displayed the same indifference in the case of Haričavank, a symbolic monument of medieval Armenian architecture, where the few fragments of the depiction of Hodegetria cannot be salvaged and preserved since a small piece of the roof has not been maintained and waterproofed (Fig.8). The Ministry has said that unless the roof situation is fixed, it will be impossible to propose a project to restore wall paintings, which will disappear in the meantime. We have been requesting this minor intervention for three years, which might be done in a single day by using specific materials to waterproof the link between the gavit’s roof and the Mother Church’s roof (Fig.9). Although the Haričavankʻ monastery is the property of the Holy See of Eĵmiacin, our project for cleaning, consolidating and conserving the remains of the wall painting must be

[1] The RA Law on the Preservation and Use of Immovable Monuments of History and Culture and the Historical Environment, Yerevan, 1998.

presented both to the Ministry's Scientific Commission and the Holy See's Commission of Architects. The issue is that one rejects the other while we await the project's presentation (Fig.10). We proposed an intervention on our initiative to waterproof the external covering above the wall of the internal painting. We are awaiting communication to leave for Yerevan and present our proposal, for which we are willing to invest the necessary funds. We did not receive a single invitation during the entire year of 2023.

Fig. 1. *10th-century wall paintings of the main altar of the Saints Peter and Paul church in the Tatev monastery complex before and after restoration of the church*

Fig. 2. *Depicts the process of removing historical plaster from the southern dome of the Saint Stephen Protomartyr Church in Lmbatavank to clean the walls, as well as our discovery of a 7th century mystical illustration in 2024*

In the Mother Church of Art'ik, where the dome does not exist, in 2017, a section of the fresco cycle in the main altar from the 7th century was restored (Fig.11). For the best possible conservation of the restored paintings, we asked for the construction of a small provisional cover of the K'obayr type to be built, but it was never made. The wall paintings are now practically outside, in the open air (Fig.12).

Fig. 3. *Due to the poor restoration of the roofing of the Kobayr chapel, as well as the infiltration of rainwater throughout the decades, high-value frescoes of the 12th century were lost*

In 2019, in Hałbat Monastery, a UNESCO World Heritage Site, we restored the wall paintings in the main altars, which had significant rainfall infiltration in the southeastern part due to the leaning external gallery (Fig.13). We notified all required authorities and obtained permission to begin soil excavations and waterproofing. When the wall paintings were restored, the Archbishop and Dean of the Diocese of Gugarac‘ Sepuh Č‘ulĵyan passed away, and everything stopped. I wrote, sent letters and contacted the Holy See of Eĵmiacin, but nothing came from it. A waterproofing project was proposed by removing the soil layer for permanent intervention; however, construction work was stopped due to the solution of a temporary cover made of sheet metal taken from the Rectory fire. For the past four years, rain has infiltrated and washed away parts of paintings from the third register of the main altar of the Holy Sign church restored by us. The indifference and lack of care for this important Armenian heritage, as in the case of a *xač‘k‘ar* installed in the masonry inside a church, is considered a historical monument and therefore protected and conserved, but the mural painting on the church’s wall no. After 4 years, rain still fell on the sheet metal retrieved from the rectory fire (Fig.14).

In 2017, we discovered the remains of wall paintings on the southwest corner of the church of Saint John Baptist in Mastarà. After completing the research and studies, we presented the cleaning, consolidation, and restoration project to the Armenian Ministry of Education, Science, Culture and Sport, and it was authorized and approved. While doing the cleanup operation, we discovered that after the church reopened to the faithful state in 1993, during the Soviet period, this church was adapted to a grain warehouse, and metal tools were used to eliminate the mortar lade, seriously damaging the remains of fresco fragments hidden under the mortar (Fig.15). Toward the end of the 18th century, during the occupation of Armenia by Tsarist Russia, a wooden mezzanine was built in the church of Mastarà, in the western apse, to house the choir after the church’s conversion to an Orthodox rite. The fresco was damaged during the construction, and the wooden structure covered a part of the Holy Knight that we discovered. In 2017, we presented the project sketch to the Ministry of Culture to detach the staircase from the wall and complete the fresco (Fig.16). I never got a response.

In 2016, we cleaned, consolidated, and restored the fresco cycle of the Surb Astvacacin church in Karmravor (Fig.17). In 2018, at our own expense, we decided to prepare illustrative panels with photos and texts in Armenian and English, as well as explanations of the various QR code works. The panels have a metal frame and are printed on rigid PVC (Fig.18). After preparing all the panels, we rented a vehicle and took them to all the churches. In 2021, we reported that the illustrative panel in Karmravor was destroyed with the intention of obtaining metal profiles and building a plate for lighting candles hidden behind the *xač‘k‘ar* (Fig.19). This was because it was no longer possible to light candles in the church to protect the restored frescoes. My project included building a new external altar layout for candle lighting by the faithful, together with the reconstruction of the portico destroyed in the 1990s. An entirely free idea was never considered (Fig.20).

In 2020, we presented an elaborate project for cleaning, consolidation, and conservative restoration of wall paintings on the west wall of Axt‘alà Monastery, 10^{th} century (Fig.21). The proposal was rejected by the Republic of Armenia's Ministry of Education, Science, Culture, and Sports, justifying the need for the drum and dome to be restored first (the project has been ready for 10 years, but no financing has been found). The drum and dome collapsed in the nineteenth century and were replaced in the Soviet period with a wooden cylinder roof to protect the interior from bad weather and rain. The frescoes on the internal walls of the Cathedral are protected from infiltration, and there is no impediment to their restoration.

Between 2015 and 2017, we conducted research, analysis, and

Fig. 4. *Damaged parts of the 7^{th} century frescoes on the walls of St. John Baptist Church in Mastara, caused by Soviet plastering and its removal in the 1990s*

surveys and presented a project for the cleaning, consolidation, and conservative restoration of two mural paintings in the Katʻołikè church of the Armenian Monastery of Dadivankʻ in Arcʻax, dating from the 9th to the 18th centuries, commissioned by the Ministry for the Protection of Monumental Heritage and Tourism Development of the Republic of Mountain Karabax. The two frescoes from 1297 represent the following scenes: on the north wall, "The stoning of Saint Stephen Protomartyr" (Fig.22), and on the south wall, "The Granting of Patriarchal powers to Saint Nicholas the Wonderworker" (Fig.23). After the second war in Karabax and before the handover of the Armenian Monastery of Dadivank to the Azeris in 2020, the Armenian authorities decided to remove the frescoes to avoid vandalism by the occupiers (Fig.24). The Armenian operators initially canceled all our restoration work from 2014 to 2017 and then removed the frescoes, damaging them (Fig.25). Our requests to see the wall painting fragments removed from Dadivank were refused and never accepted. We intend to collaborate to restore wall paintings and display them to the public. We hope that the opportunity to achieve this goal will be created.

Fig. 5. *The bad condition of the Kobayr chapel's roof*

Fig. 6. *Ara Zarian and Christine Lamoureux's 2021 project to clean, repair, and conserve the frescoes of the Kobayr chapel, waiting for the gable roofs to be restored*

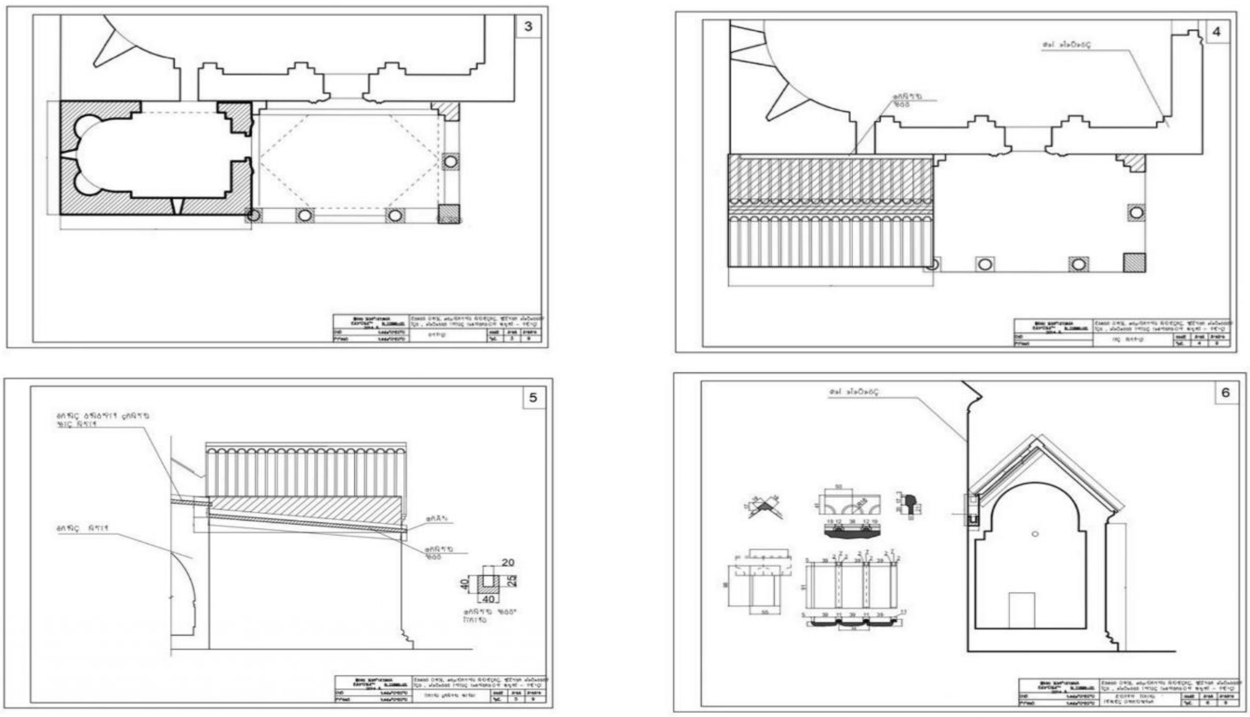

Fig. 7. *Architect Gor Mikayelyan's restoration project for the Kobayr chapel roofs was proposed in the 1990s but never implemented*

Fig. 8. *Fragments of a mural painting dated 1235 were found on the upper part of the entryway to Holy Mother of God Church from the Harich Monastery*

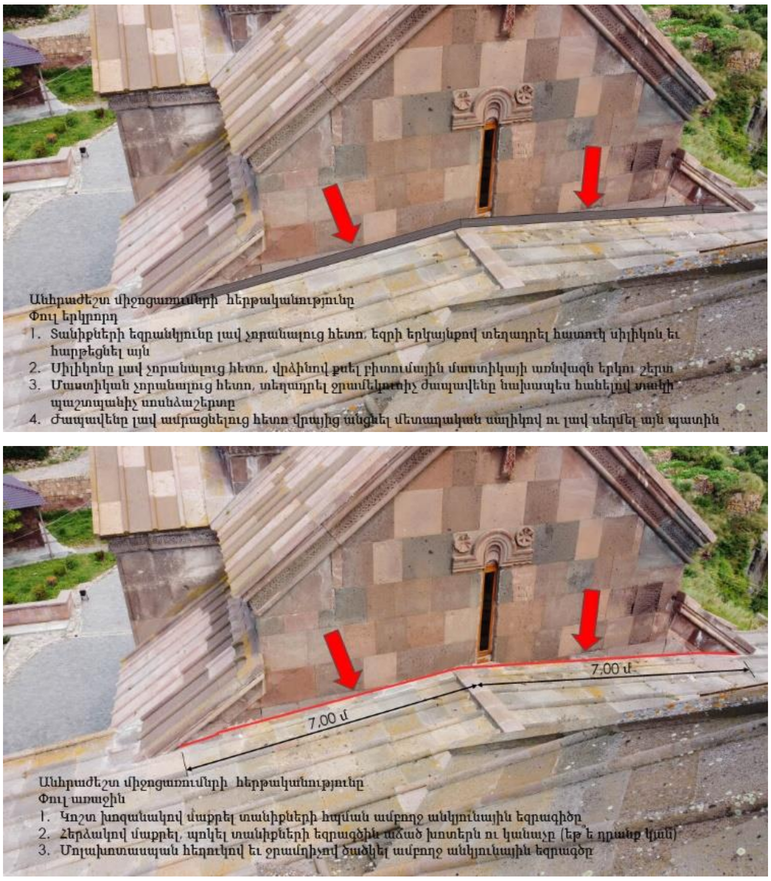

Fig. 9. *Architect Ara Zarian's proposal for waterproofing the gable roof of Harichavank courtyard in 2021 is awaiting approval from the Mother See of Holy Etchmiadzin*

Wall paintings in Armenian churches are historical monuments that must be preserved and are an inseparable part of the monumental architectural heritage of each existing church.

Results and Discussion

Between 2012 and 2019, the wall paintings in the Armenian churches underwent conservative restoration, consolidation, and cleaning. The authors also mentioned the results of the absence of local professionals with fresco restoration experience and knowledge, as well as the lack of interest from the authorities and the lack of expertise. The materials, techniques, and procedures used for the interventions on the wall paintings in the churches of Artzakh and Armenia are the same as those used during the restoration of frescoes in churches in the Veneto region in Italy. Over the

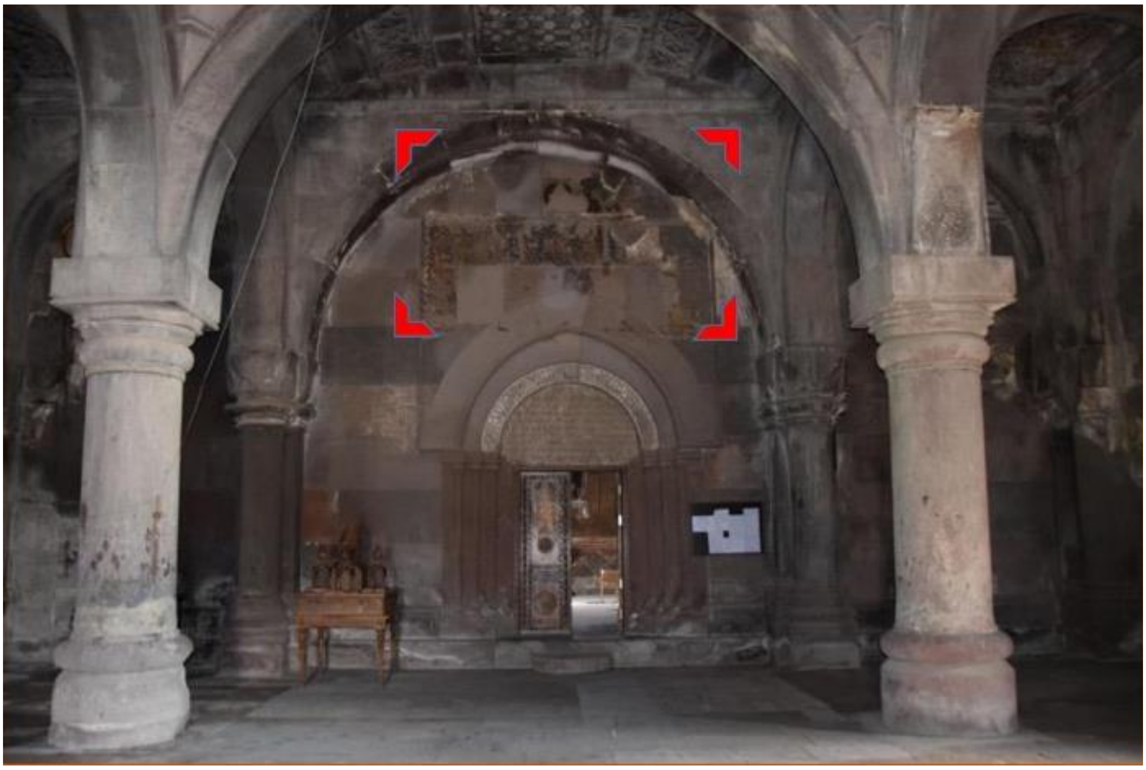

Fig. 10. *Ara Zarian and Christine Lamoureux's project to clean, maintain, and restore the Harichavank frescoes, approved by the RA Ministry of Education, Science, Culture, and Sport in 2024, is now awaiting approval from the Mother See of Holy Etchmiadzin*

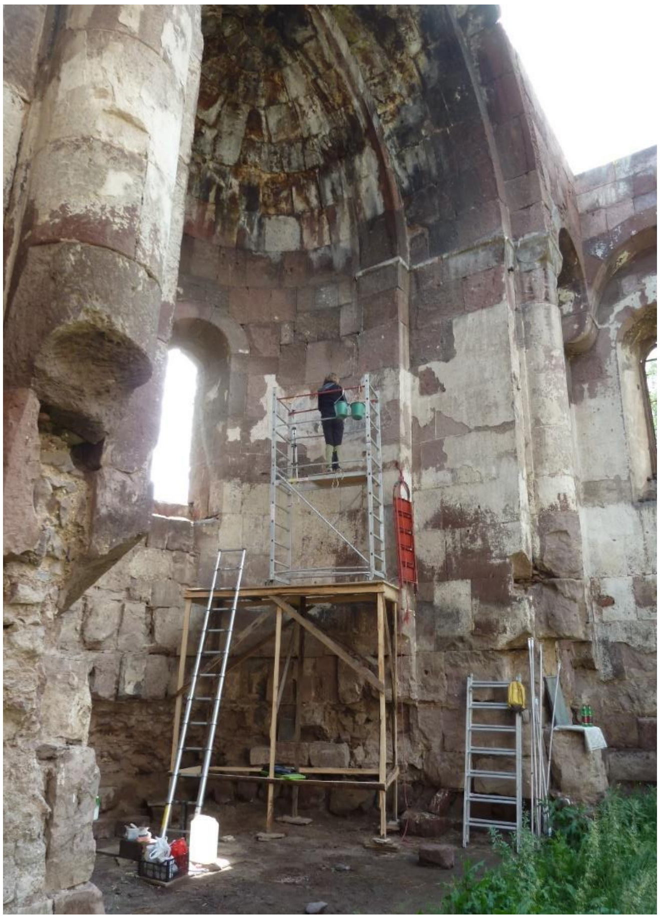

Fig. 11. *The restoration of a section of the 7th-century fresco preserved on the south wall of the main altar at St. George Cathedral in Artik*

course of a professional career spanning approximately 35 years, they restored approximately one hundred frescoes after being hired and approved by religious organizations as well as the province of Veneto's Superintendence for Heritage Cultural Institutions. The technologies, materials, and applications that the Minister of Culture, Science, Education, and Sports of the Republic of Armenia sought during the 2022 session of the International Scientific Commission are clearly visible across this time frame. These insights were considered and used to make changes and improvements to the restoration and conservation projects that would be presented shortly.

Discussions about the usage of novel nanotechnology materials, which have yet to be tested but are commercially marketed by the companies that create them, require time, which is insufficient. It was determined to employ traditional approved and proven materials, which have demonstrated great effectiveness and long-term durability, with at least 30 years of evidence of nontolerance to environmental changes. In any case, we decided to use next-generation materials for future work in Armenian churches.

Fig. 12. *The same mural after restoration in 2016*

Fig. 13. *A general view of the Haghbat monastery complex from the southeast*

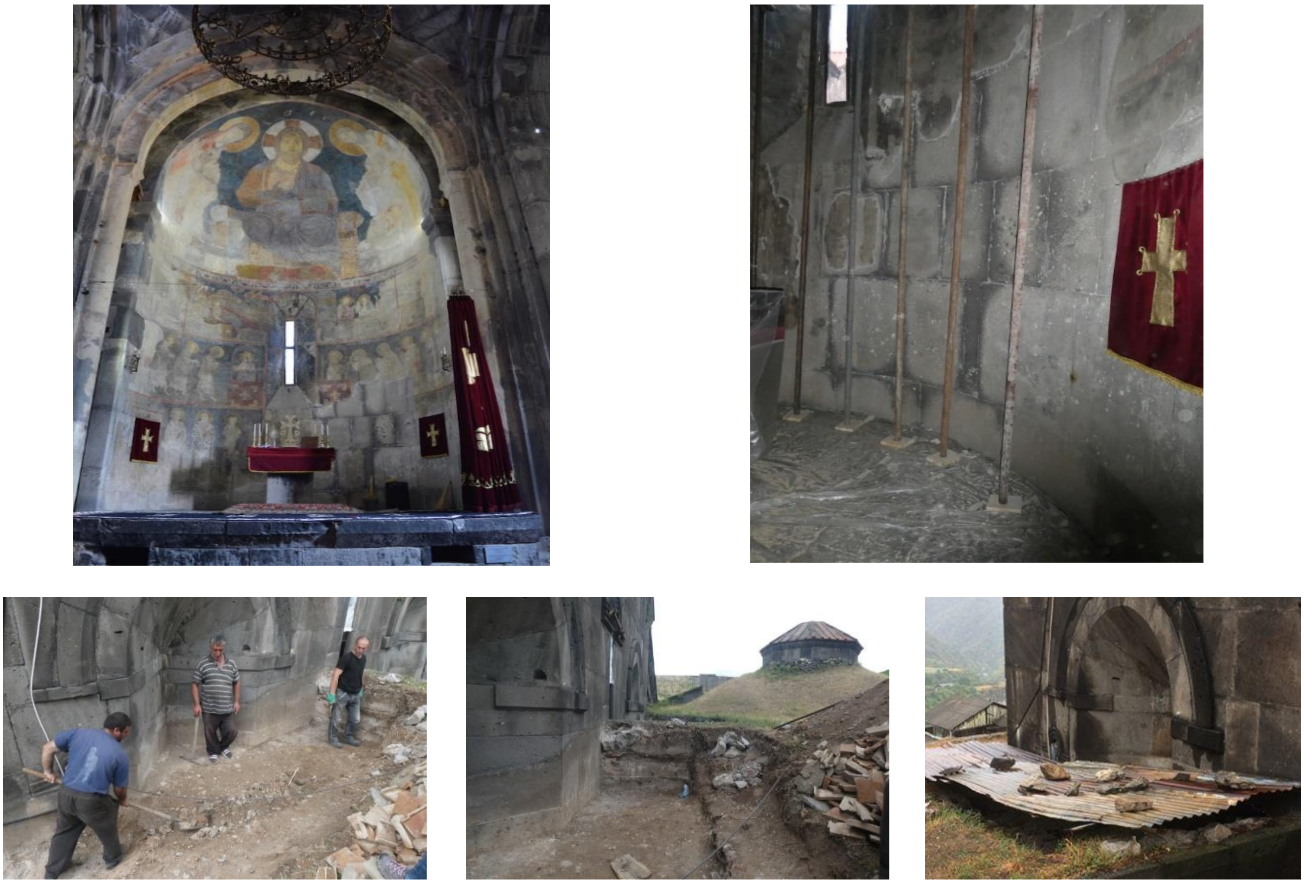

Fig. 14. *The damages caused by humidity to the wall of the mural painting restored by Ara Zaryan and Christine Lamoureux in 2019 of the main altars of the Holy Sign Church of the Haghbat Monastery complex, as well as the necessary measures and the unfinished status as of today*

Fig. 15. *An example of the brutal destruction of the fresco remnants discovered in 2015 by Ara Zaryan and Christine Lamour of St. John Baptist Church in Mastara*

Fig. 16. *The fragments of a fresco from the 7th-century can be found on the church's southern wall beneath the wooden wheels of an 18th-century lodge. Ara Zarian and Christine Lamoureux restored the wall painting in 2016*

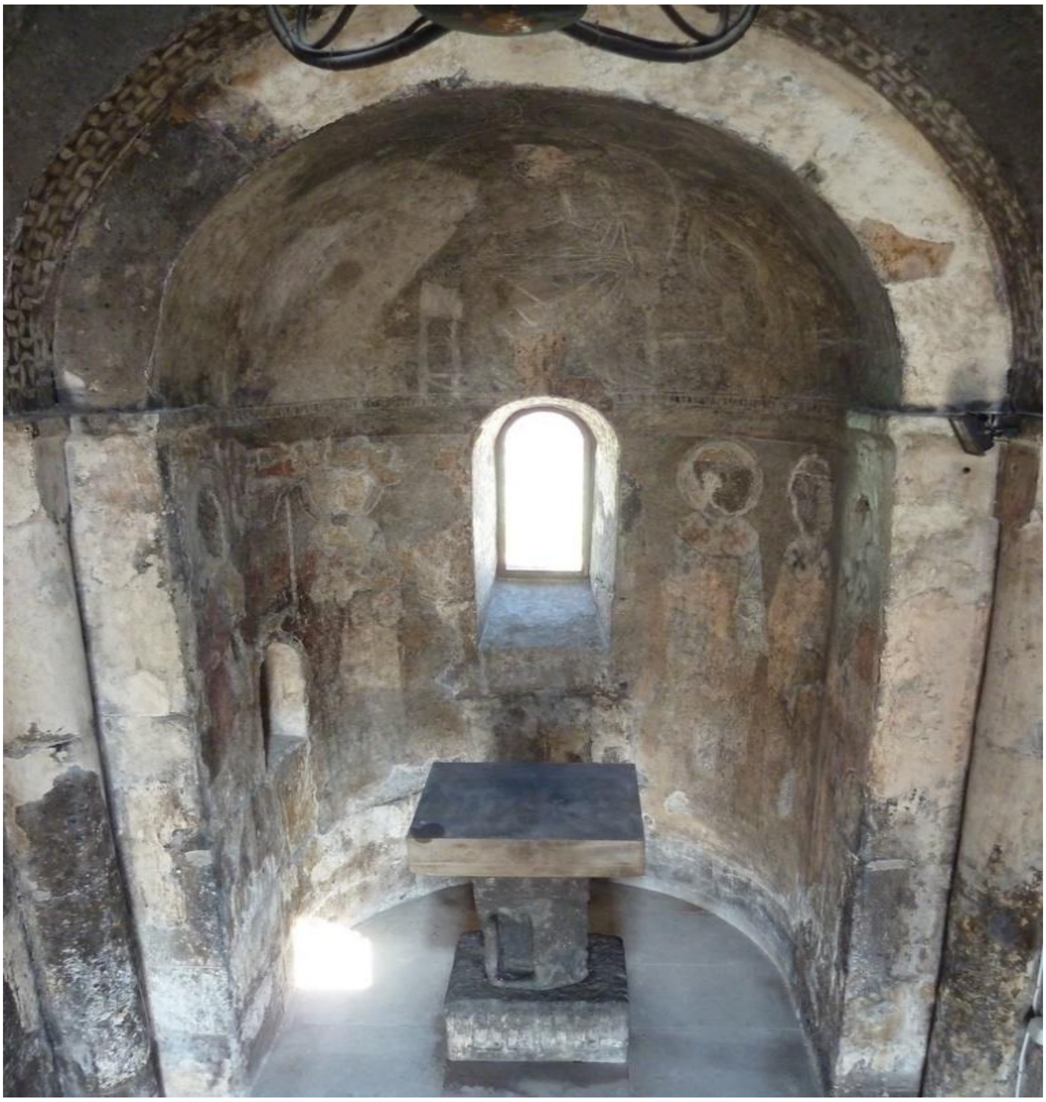

Fig. 17. *After completing the works of cleaning, fixing, and conservation restoration of the frescoes on the main altar of St. Holy Mother of God Church of Karmravor in 2016*

Conclusion

1. In Armenia there is no complete inventory of church wall painting fragments and scenes.
2. Without any knowledge of the monumental heritage, it is impossible to improve and legalize cultural heritage.
3. In Armenia there is no school of wall painting restoration and the few specialists who study, conserve, and restore wall paintings are often criticized.
4. Based on the examples presented above, it can be concluded that political and religious authorities do not pay adequate attention to the protection of pictorial heritage in Armenian churches due to a lack of professional training in the field.
5. We propose a rethink and thorough study to maintain what little survives of the beautiful wall paintings in Armenian churches.
6. We offer our expertise in creating a thorough catalog of all wall paintings in Armenian churches funded by the government or benefactors.

Fig. 18. *The process of preparing bilingual explanatory panels near the frescoes restored by us*

Fig. 19. *2022, after destroying the Crimson's explanatory panel and building a pool of candlelight from its metal rods*

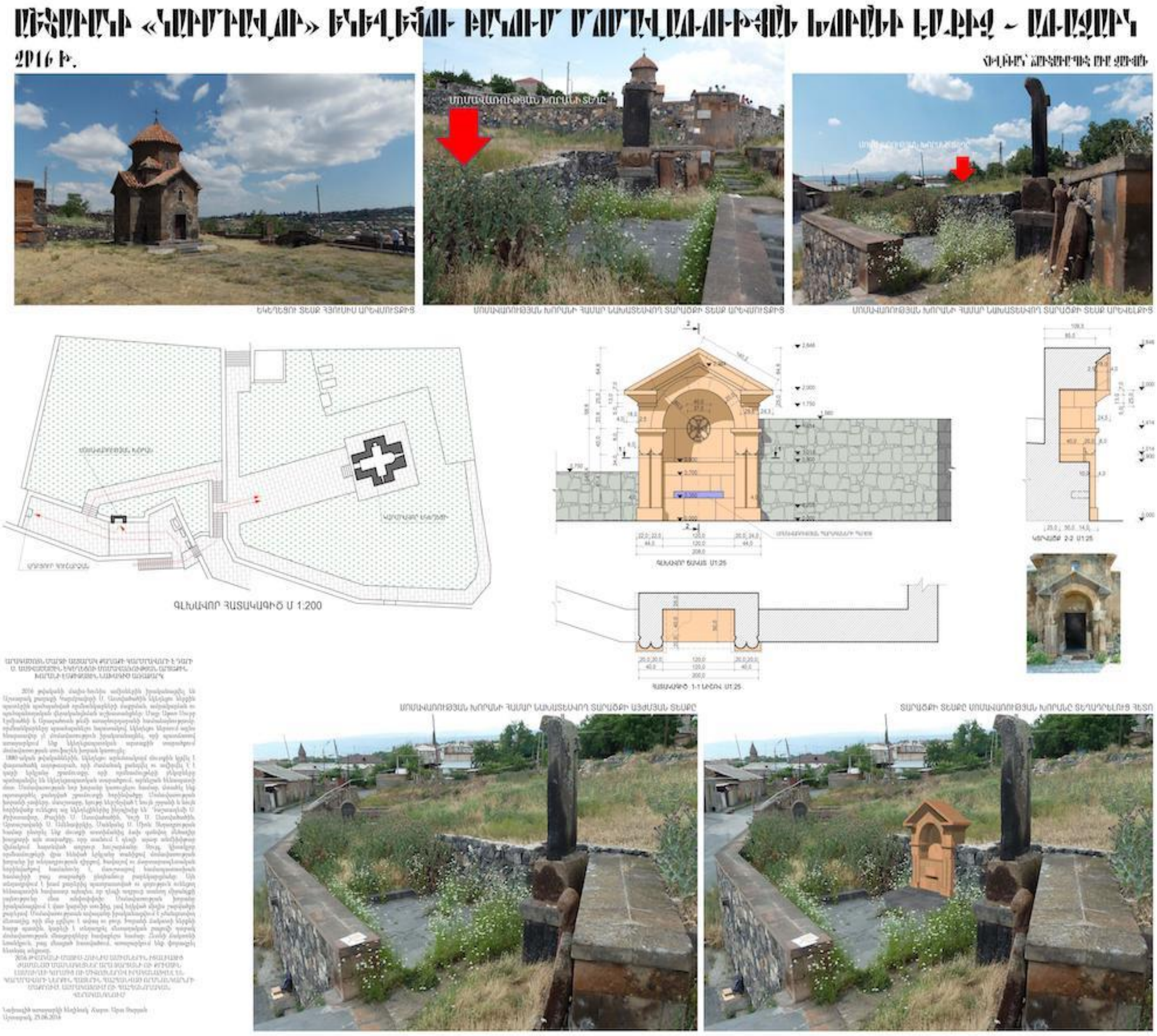

Fig. 20. *After restoring Karmravor's murals, architect Ara Zarian proposed the unrealized candlelight altar project*

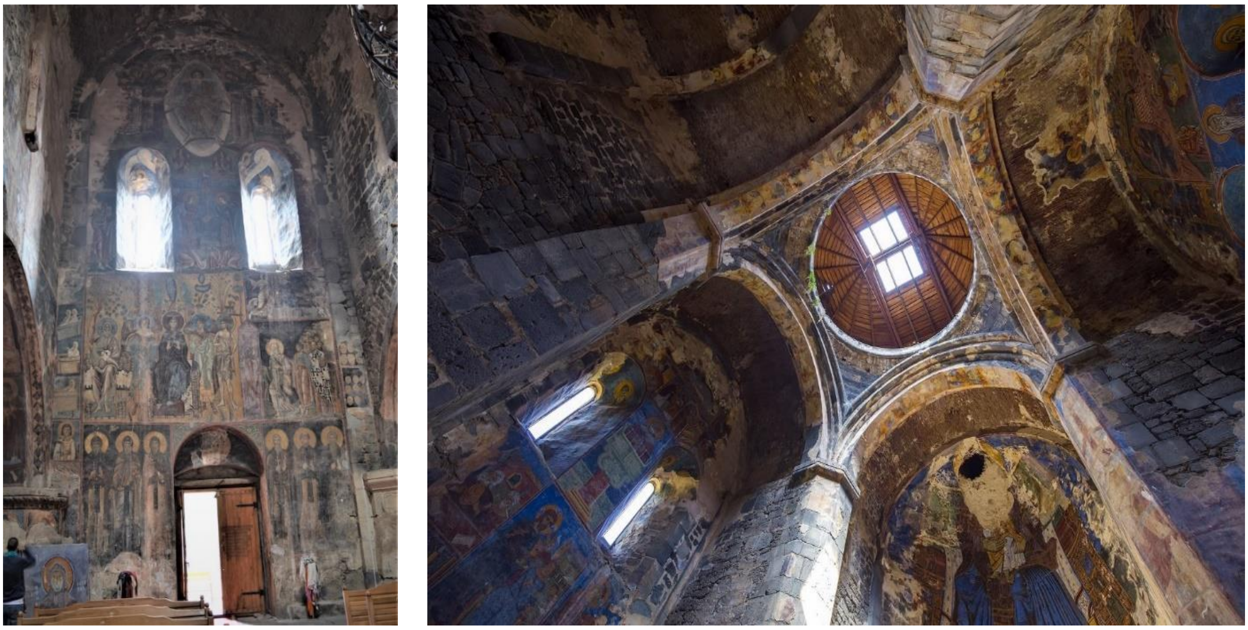

Fig. 21. *The interior walls of St. Holy Mother of God Church at Akhtala Monastery are completely frescoed, dating from the XII-XIII centuries*

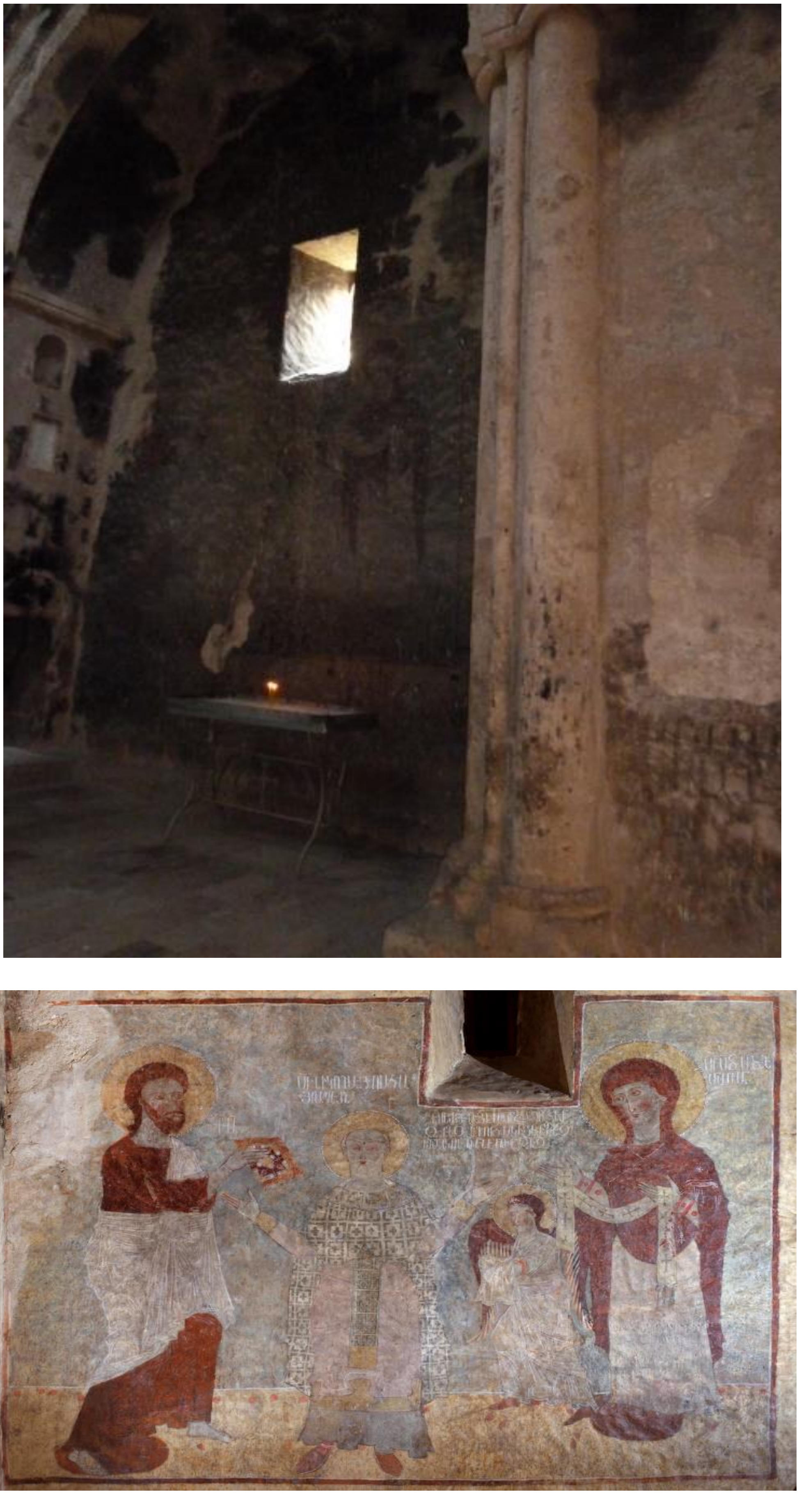

Fig. 22. *Before and after restoration of the 1297 mural on the south wall of the Cathoghike Church of St. Holy Mother of God in Dadivank Monastery by Ara Zarian and Christine Lamoureux from 2015 to 2017*

Fig. 23. *Before and after restoration of the 1297 mural on the northen wall of the Cathoghike Church of St. Holy Mother of God in Dadivank Monastery by Ara Zarian and Christine Lamoureux*

Fig. 24. *2022, after demolishing the mural on the northern wall of the Cathoghike Church of St. Holy Mother of God*

Fig. 25. *Dadivank Monastery Cathoghike St. Holy Mother of God Church, the mural is being removed from the wall for the safety of it*

Conflict of Interest

The author declares no conflicts of interest.

Funding

This research did not receive any financial support.

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AGHVANK ARCHITECTURE IN SCIENTIFIC LITERATURE

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Abstract: *In recent decades, articles on Aghvank architecture have been published in scientific literature, showcasing notable differences from materials published before the 1970s. These newer publications present conflicting results and conclusions, reflecting diverse scientific approaches. As a result, the Azerbaijani scientific community portrays the entire Christian culture of Artsakh, particularly its architecture, as a component of the Aghvan heritage. This paper comprehensively reviews existing scientific materials on Aghvank architecture, spanning publications from both the Soviet and post-Soviet eras, as well as compares the articles authored by Azerbaijani scholars with those that have been written in foreign languages and published in periodicals. After conducting research, it is evident that Azerbaijani historians have increasingly attempted to claim the Christian culture and architecture of Artsakh as their own over the past 40 years. This has led to a loss of objectivity and scientific approach towards existing materials and methods. The study aimed to show the dynamics of the "scientific study" of Azerbaijani architecture, the editing of the "new history" of the medieval culture and architecture of Aghvank in the Caucasus in recent decades, to highlight the main contradictions evident in the results of research by Azerbaijani and foreign scientists. Today, in the context of the occupation of the entire territory of Artsakh and its architectural heritage, such a discovery is becoming increasingly important.*

Keywords: *Artsakh, Bun Aghvank, Aghvank architecture, Sudagilan, Mamrukh, Nyugdi.*

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Received: 15.06.2024
Revised: 08.07.2024
Accepted: 17.07.2024

Introduction

Currently, Azerbaijan has militarily occupied the entire territory of Nagorno-Karabakh, which historically belonged to Artsakh, forcibly displacing the Armenian population that has resided in Artsakh for centuries. It is noteworthy that, until the 1920s, there was no mention of a nationality known as Azerbaijan among the people of the Caucasus [1]. Azerbaijan now faces the significant challenge of crafting a "history" to justify all its actions against the Artsakh population. Under these conditions, it is vital to consider how the existing architecture in Azerbaijan was presented from the beginning of the 20th century to the present day. The works of Russian and Soviet historian, archeologist, and Caucasologist I.P. Sheblikin [2], Soviet art critic, researcher of Near and Middle East architecture L.S. Britanitsky, and Soviet art historian, orientalist, and academician B.V. Weimarn [3] on Azerbaijan's medieval architecture, which were published until the 1970s, were examined.

Special attention was paid to the works of Azerbaijani scientists Mikael Huseinov, Sadikh Dadashev [4-6], Vagab Salamzadeh, and Kamil Mamedzadeh [6], which were published *pre-1970s and post-1970s*, comparing the content and methodological changes that developed in the last few years.

Russian archaeologist, ethnographer, and anthropologist Viktor Shnirelman and American scientist, Caucasologist, specialist in Armenian and Caucasian Aghvan history Robert Huysen also referred to Aghvan architecture and culture in the territory of Azerbaijan. And, certainly, the studies of the Russian archaeologist, art critic, and historian Anatoly Jacobson on the Armenian architecture of Artsakh are vital.

This study compares the aforementioned works from recent years with the studies conducted by non-Azerbaijani scientists during the same period, highlighting the modernity and novelty of this research.

This article aims to uncover the falsehoods which the scientific community of Azerbaijan–consistently attempts to present as new scientific findings and discoveries to the world under the state's patronage and in strict accordance with the prescribed task. Now, it becomes more problematic when the scientific world of Azerbaijan, deprived of healthy scientific criticism, is seeking to justify its persistent occupation policy toward Armenians, Armenia, and Artsakh. This issue is particularly pressing today, especially considering that the cultural heritage crafted by the Armenians remains entirely unprotected in Artsakh and is in a highly endangered condition in Syunik.

Materials and Methods

The Azerbaijani scientific community now portrays Aghvank architecture, especially cult architecture, as an inherent component of Azerbaijani architecture. Consequently, to provide a comprehensive overview of studies on Aghvank architecture, the scientific literature on Azerbaijani architecture was examined and analyzed.

The analysis of scientific studies and publications, depending on the period and the authors, was chosen as a method for the research. Two main stages were considered for comparison. The first stage includes publications from the 40s to the 70s of the XX century. The second stage comprises publications from the period of political independence and free scientific activity in Azerbaijan, which covers the period from the 70s to the present day.

Results and Discussion

Caucasologist Ivan Sheblikin conducted the first scientific study on Azerbaijan's history, culture, and architecture [2]. This study presents descriptions of Azerbaijan's main architectural monuments in the XI–XIV centuries and provides a brief overview of the architecture preceding that period. The work describes numerous monuments: castles, palaces, tombs, and palace structures, which were documented and studied in the 1930s. There is not even a hint of a Christian structure here. The latter are not considered structures and monuments of Azerbaijani architecture. Moreover, nothing is said about the medieval monasteries and churches of Aghvank.

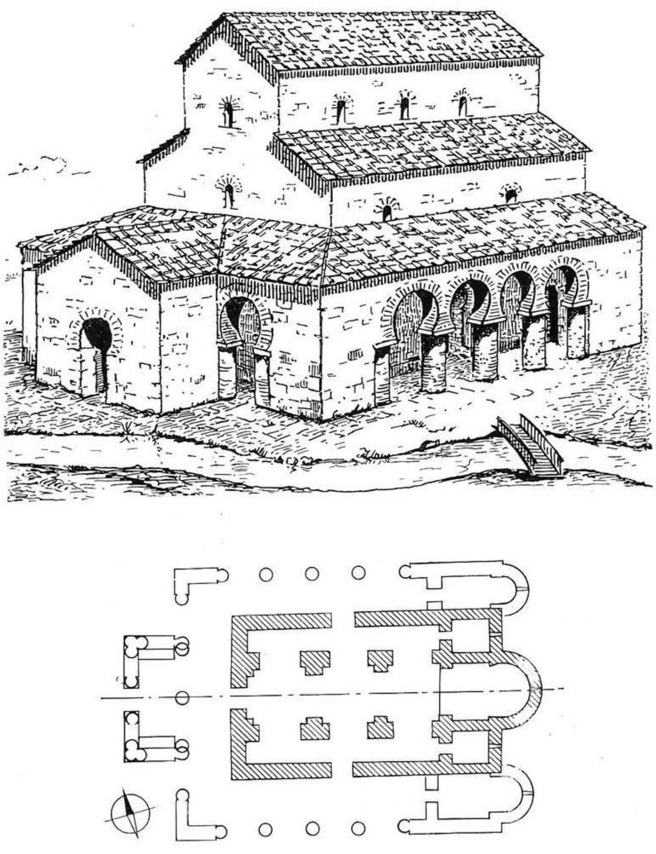

Fig. 1. *Plan and restructuring of the basilica temple near Kum village*

The second significant work on architecture within the territory of Azerbaijan was published in 1947, under the editorship of S.A. Dadashev and M.A. Huseinov [4]. The first part of the book focuses on the period predating the 11th century. Authored articles include "The Architecture of Azerbaijan until the 5th Century BC" by N. Gorchakova, K. Mel, and P. Sheblikin; "Monuments of the Kum and Lekit Settlements" by P. Baranovsky; and "8^{th}-11^{th} Century Monuments" by P. Sheblikin. Of particular significance in the book is Baranovsky's article, which presents, for the first time, the early Christian basilica temple of Kum village on the left bank of the Kur river in the Kakh region of Azerbaijan (Figs. 1,2), as well as the round temple of Lekit village in the same region (Fig. 3) [4].

Fig. 2. *Kum, general view of the basilica from the southwest and outer colonnade*[1]

In 1948, the Academy of Architecture of the USSR released a book titled "Architecture of Azerbaijan" [5,6], under the authority of S.A. Dadashev and M.A. Huseinov. Here, Aghvank is mentioned only in the introduction, in two sentences: "In the Roman era, the state that occupied the territory of Azerbaijan was called Albania. There is a mention of the Albanian cities in Ptolemy (first half of the 2nd century)" [4].

Russian historian and orientalist Kamilla Trever studied the history and culture of Aghvank. Her work "Outlines of the History and Culture of Caucasian Albania, IV century BC - VII century AD" was the first generalizing work dedicated to the issues of the history, socioeconomic relations, and material culture of Aghvank. In the section concerning the architecture of Aghvank [7], the monuments of Kum and Lekit villages are discussed, citing the results of Baranovsky's studies. The ruins of the early medieval church and adjacent buildings discovered by R.M. Vaidov during the excavations of Sudagilan in 1949 near Mingechaur, on the city's left bank (Fig.4) [8], are only briefly touched upon in the discussion. Nevertheless, the broken stone inscriptions in the church ruins [9] allows to date it to the 7th century [10].

The literature also mentions the chapel built near the village of Nyugdi in the Derbent region of Dagestan at the place of martyrdom of St. Grigoris, where St. Grigoris Church is located [11].

In 1968, the book "Architecture of Azerbaijan XVI-XIX centuries" was published by the publishing house of the Academy of Sciences of the Azerbaijan SSR, authored by A.V. Salamzade and edited by M.A. Huseinov. The first chapter of the book delves into cult structures, where not a single word is mentioned about Christian cult structures, particularly Aghvanic and, as is often presented now, Udi cult structures [12].

[1] https://commons.wikimedia.org/w/index.php?curid=109991412

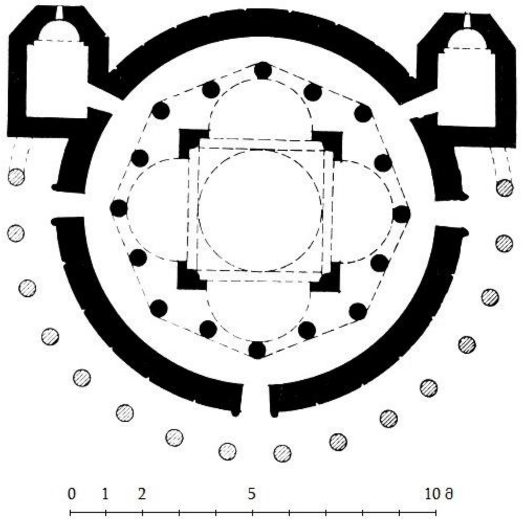

Fig. 3. *General view and plan of the ruins of the Round Temple in Lekit village*[2]

From 1966 to 1977, the Civil Construction and Architecture Committee under the USSR's Ministry of Construction, in collaboration with the Research Institute of Theory, History, and Prospective Problems of Soviet Architecture, released the 12-volume "History of World Architecture." This monumental work is the most extensive and authoritative publication of the professional literature in this field [13]. The architecture of Azerbaijan is presented in the 6th chapter of the 8th volume [14]. The first sub-chapter is about the architecture of Azerbaijan in the IV-VII centuries [11]. "Monuments of Christian religious construction are the nearby basilica in Kum village and the round temple in Lekit village" [14]. The text describes the basilica of Kum village and the rotund temple of Lekit village in great detail. It also mentions the relationship between these structures and the similar religious structures of the same period in Armenia, Georgia, Syria, and Byzantine. None of the following chapters discuss Christian architectural structures as a part of Aghvani or Azeri architecture.

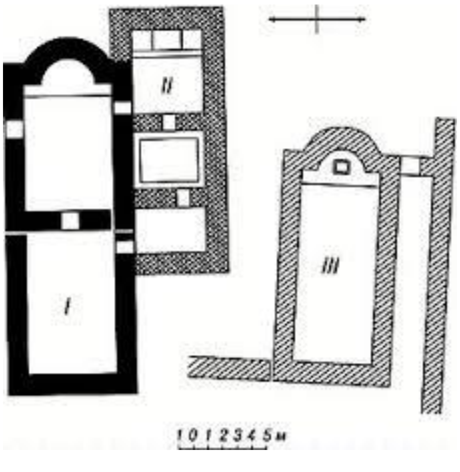

Fig. 4. *Plan of the foundations of the Sudagilan church complex*
(I-VII-IX centuries, II-VIII-IX centuries, III-V-VI centuries) and headstone

R.B. Geushev, a scholar from Azerbaijan who has studied the history of Aghvank, argues that the Gandzasar monastery is not Armenian but Aghvanic [15]. In 1978, Geushev defended his doctoral thesis in Tbilisi, titled "Christianity in Caucasian Albania," and subsequently published it [16]. The scientific novelty of the topic is: "The scientific novelty of the work lies in the fact that, to the best of the available capabilities, for the first time in a monographic plan a relatively complete history and history of the material culture of Christianity in Caucasian Albania is given as a natural part of the Azerbaijani people history" [16]. Here, the

[2] https://xn--h1ajim.xn--p1ai/index.php?curid=16909099

first attempt is made to own the monastic monasteries of Artsakh and Utik, declaring them aghvanic, regardless of the period and region. "The map of the distribution of monastic buildings in Azerbaijan shows that almost all bishoprics had several monasteries. Albanian monasteries were also built outside Albania" [16].

In the following years, Azerbaijani scientific thought exhausted its studies into the history and theory of Aghvank architecture itself and set a task to present the culture, architectural structures, and monuments on the right side of the Kur River as Aghvanic.

Soviet orientalist Zia Buniatov played an important role in this issue, providing the historical basis for the privatization of Armenian religious structures. The primary focus of the scientific debate has shifted from the reliability of scientific evidence and research to plagiarism and deliberate mistranslation of literary sources.

Soviet and Russian archaeologist and ethnographer Victor Schlimerman has deeply studied the Armenian-Azerbaijani conflict with its cultural and political issues. Speaking about the activity of Azerbaijani scientists, led by Z. Buniatov, distortions of historical materials and sources, he notes: "Another way to downplay the presence of Armenians in ancient and medieval Transcaucasia and belittle their role is to republish ancient and medieval sources with notes, replacing the term "Armenian state" with "Albanian state" or other distortions of the original texts. During the period of the 1960s-1990s, numerous reprints of primary sources were published in Baku, which academician Z. M. Buniyatov was actively involved in.

However, in recent years, when discussing ethnic processes and their role in the history of Azerbaijan, Azerbaijani authors sometimes generally avoid discussing the appearance of the Azerbaijani language and Azerbaijanis there, leading the reader to believe that they have existed there from time immemorial. Hardly Azerbaijani historians did this solely out of their own free will; they were likely influenced by the orders of the party and government structures of Azerbaijan" [17].

Soviet archeologist, art and architecture history researcher A.L. Yakobson has published many articles and works on Armenian architecture and, in particular, Gandzasar Monastery [18]. Speaking about the Gandzasar monastery, he mentions its belonging to the Armenian architectural school and strongly criticizes its Albanianization. "It is not clear why the authors needed to distort the semantic and artistic content and origin of the Armenian medieval decorative art, easily and mindlessly "connecting" it either to the art of Albania, which did not exist at that time (and in the authors' understanding, to the art of Azerbaijan), or directly to the art of Azerbaijan. Our summary is short. It is with regret that we have to admit that the article by D. A. and M. D. Akhundov is biased in its meaning and spirit. This kind of article, in our opinion, can only disorient the reader" [19].

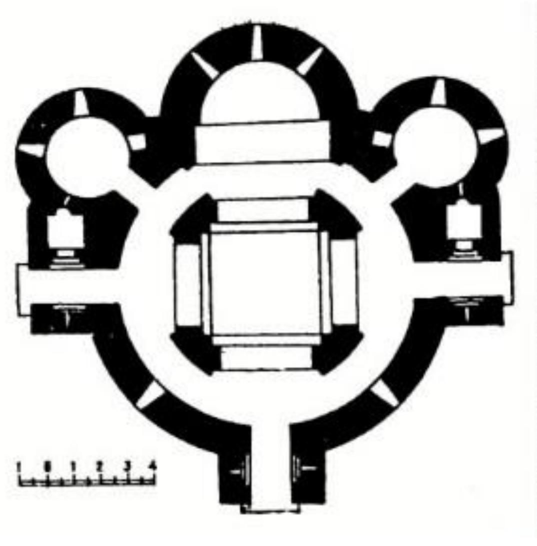

Fig. 5. *A medivial Christian round church near the village of Mamrukh in the Zakatala region of Azerbaijian*

Azerbaijani scientist G.S. Mammadova defended her doctoral thesis on the topic "Cultural Architecture of Caucasian Albania" [20] and, in 2004, published the monograph "Architecture of Caucasian Albania" with an additional edition [21]. In her research, the author also describes the round church near the village of Mamrukh (Fig. 5), expanding the influences that the Aghvanian, namely Azeri architecture left on the neighboring countries. The third chapter of the book talks about the Aghvank architecture of the 8th-10th centuries. Here, the author separates the architectural style of the Syunik school from the Armenian school and associates it with the influence of Aghvank. "However, the architecture of Caucasian Albania cannot be complete without religious structures on the territory of neighboring countries in areas historically associated with Caucasian Albania. In Syunik, roofing slabs replaced tiles earlier than in other areas. The trumpet arch was preserved here for a long time as the most effective design for changing from the base square to the drum. These and other features distinguish the architecture of Syunik from the Armenian one" [21]. The author unequivocally classifies the monastic complexes and religious structures of all later centuries, including Gandzasar, Khutavank, Amaras, Dadivank, and other monasteries, to the "Aghvanic" school of architecture, accusing Jacobson of partiality and unprofessionalism [21].

In these years, another thesis has been defended with similar topicality and goals. Candidate of architecture A.T. Salimova in 1998 defended a thesis titled "The creative roots of the Emergence of the cult ritual architecture of Caucasian Albania". From 1993 to 1996, she participated in several conferences and published articles on the aforementioned topic in Baku (Fig. 6) [22].

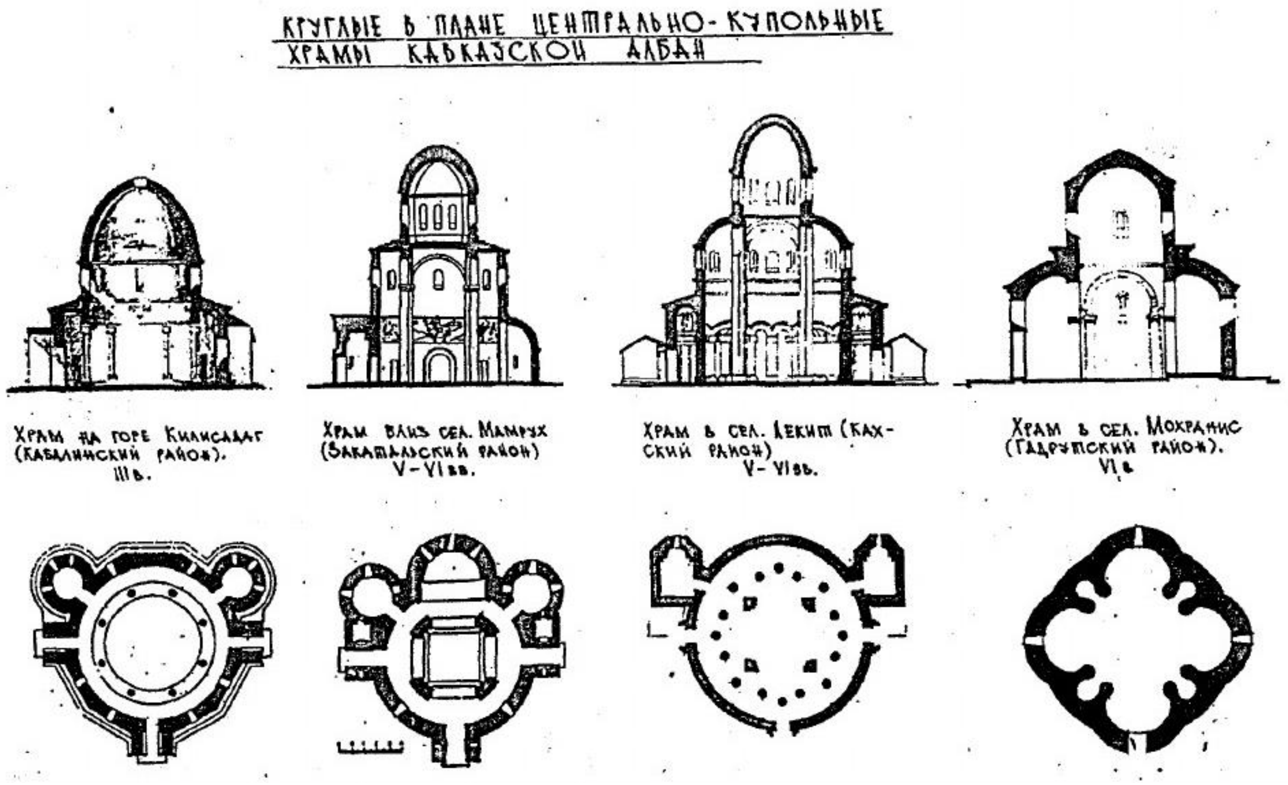

Fig. 6. *A list of all churches from A. Salimova's thesis, where the church of Mokhrenes village of Dizaki, which is clearly different from the first three churches, is presented as an aghvanic*

Azerbaijani historian, doctor of historical sciences, and professor F. Mamedova is also one of the researchers of the history and culture of Aghvank in the Caucasus. In 1986 her monograph "Political History and Historical Geography of Caucasian Albania" was published [23], which was strongly criticized both by scientific experts [24] and Azerbaijani scientists. Shnirelman considers her the main propagator of the "Albanian myth" [17], and Azerbaijanis, in the person of Yaghub Makhmudov, director of the History Institute of the National Academy of Sciences of Azerbaijan, consider her a "traitor to the fatherland" and "Armenian spy" for including Great Haik on the "Aghvank and neighboring countries" map[3].

Mamedova herself states that Heydar Aliyev personally demanded from F. Mamedova that every book published by Armenians be subject to scientific criticism[4].

[3] Albania or Atropatena? How they “compose” the ancient history of the Caucasus Archival copy dated January 6, 2014, on the Wayback Machine. "Echo" (Baku), No. 76 (1316), April 29, 2006.

[4] "Echo" newspaper, No. 76 (1316), April 29, 2006: "Armenians published 15-19 books a year, and Heydar Aliyev demanded scientific criticism for each book. So I began to untie the Armenian knot. One map is considered 4 years of work by a scientist. And I have 7 such maps. I thought that I would be praised for these maps but it turned out to be the opposite... ".

In 2005, her book "Caucasian Albania and the Albanians" was published, in which Mammadova albanianizes not only Eastern Armenia but also Kilikia, its people, kings, clergy, their spiritual culture, literature, jurisprudence, and material values [25].

The modern American scientist, Caucasologist Robert Huysen, also studied the history of Armenia and Caucasian Aghvank [26]. Speaking of the theory of literature related to the topic, he notes the unreliability of many historical publications from the Soviet period. «Scholars should be on guard when using Soviet and post-Soviet Azeri editions of Azeri, Persian, and even Russian and Western European sources printed in Baku. These have been edited to remove references to Armenian and have been distributed in large numbers in recent years. When utilizing such sources, the researchers should seek out pre-Soviet editions wherever possible». Unfortunately, Azerbaijan behaves barbarically with the cultural values that cannot be owned, such as cross-stones. The Azerbaijani government has not yet found a way to take possession of them (Figs. 7,8)[5].

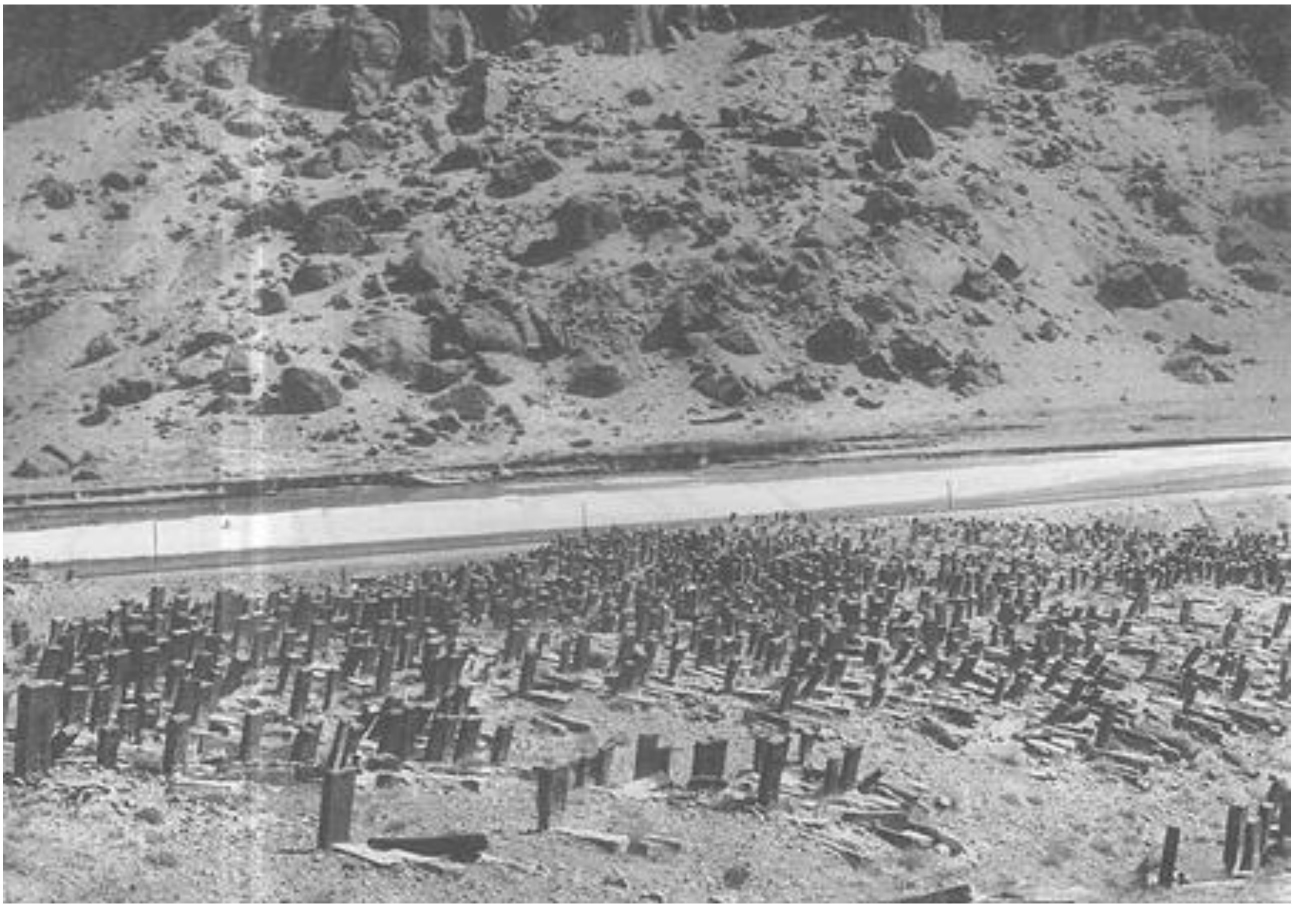

Fig. 7. *Jugha cemetery before destruction*

Fig. 8. *Satellite images of the cemetery taken on 23.09.2003 and 28.05.2009. The shadows from the cross-stones are no longer visible*

[5] High-Resolution Satellite Imagery and the Destruction of Cultural Artifacts in Nakhchivan, Azerbaijan https://www.aaas.org/resources/high-resolution-satellite-imagery-and-destruction-cultural-artifacts-nakhchivan-azerbaijan

Conclusion

Research on the culture and architecture of Aghvank remains a subject of great interest, with different points of view being expressed in various scientific studies. In this article, we reviewed and compared studies carried out mainly by Soviet scientists before the 1970s with the articles written after that period. Our analysis showed that:

1. It should be noted that in the materials published before the 1970s, the architecture of Aghvank was only represented by early Christian monuments that were found on the left bank of the Kur River in Aghvank itself. As a result, it was not considered a part of Azerbaijani architecture. These articles were written by both Azerbaijani and Russian scientists.
2. In the 70s of the 20th century, a new wave began when Azerbaijani authors not only included the entire culture and architecture of Artsakh and Utik in Aghvan architecture but also blamed those scientists who denied that the mentioned monuments belonged to Aghvan, that is, to Azeri.
3. After the collapse of the Soviet Union, during the political and scientific independence of Azerbaijan and the following years, scientific theses are being defended in Azerbaijan, where the trends of privatization of Armenian architecture are acquiring so much momentum that an attempt is already being made to alienate Syunik from Armenian culture, as well as the architectural schools of Kilikia.
4. Powerful state patronage in scientific policy has been condemned by Russian and Western scientists as unscientific and false approaches.
5. The authorities of Azerbaijan persistently and continuously establish a scientific foundation to support the implementation of a well-developed strategic plan aimed at occupying Armenia.
6. All the monuments in Azerbaijan that cannot be privatized (cross-stones, churches, and settlements) are at risk of vandalism and destruction.

Conflict of Interest

The author declares no conflicts of interest.

Funding

This research did not receive any financial support.

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CALCULATION FEATURES OF VERTICAL SETTLING TANKS FOR HEAVY METAL - CONTAINING WASTEWATER TREATMENT

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Abstract: *The article discusses the treatment of wastewater containing heavy metal salts before releasing it into natural water bodies or the urban drainage system. The focus is on environmental protection, human health, and the potential for recovering valuable metals from wastewater. A vertical settling tank was selected for its cost-effectiveness in treating metal-containing acidic wastewater. The article provides a general method for calculating these settling tanks during reagent sedimentation, which can be used to remove various types of heavy metal salts. For this purpose, all calculations related to the use of reagents (their quantities, volumes of reagent storage, solution tanks, and neutralization chambers) were conducted in advance. Additionally, corresponding chemical equations for the reagents and various acids, as well as the equations for the reactions occurring between the reagents and heavy metal salts, were formulated.*

Keywords: *salts of heavy metals, neutralization reactions, hydroxide compounds, wastewater, vertical settling tank.*

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Received: 26.06.2024
Revised: 17.07.2024
Accepted: 27.07.2024

Introduction

Industries involved in the chemical and electrochemical treatment of metals are among the most harmful to the environment. The discharge of wastewater containing poorly treated heavy metal ions into natural water bodies causes significant environmental damage, and the release of such untreated wastewater into water bodies must be entirely prevented [1-3]. Consuming seafood from such water bodies is fraught with dangerous consequences for humans, leading to severe diseases of the nervous system, blood vessels, heart, and liver [4-6]. It should also be noted that various technological processes in metalworking plants consume large amounts of water[1,2]. Therefore, the development of new or improved methods for deeply purifying this contaminated water is highly relevant from an environmental perspective[3] [7]. Deep purification will not only improve the ecology of the surrounding environment but can also serve as a source for obtaining a number of valuable metals [8-13].

Wastewater containing heavy metal ions, including valuable non-ferrous metals, is currently treated using various methods [14-18]. Electrochemical methods, based on physical chemistry, electrochemistry, and chemical technology, involve separation and conversion processes or a combination of both.

These methods are quite complex, and the mechanism and rate of each stage depend on many factors, which are difficult to ensure simultaneously.

Materials and Methods

The calculation methodology is based on reagents' interactions with acids and heavy metal salts. This method includes equipment calculation that neutralizes acidic metal-containing wastewater and a generalized calculation of the vertical settling tanks intended for their purification.

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[1] Water management in the steel industry. https://worldsteel.org/wp-content/uploads/Water-management-in-the-steel- industry.pdf
[2] Properties and Uses of Steel and Stainless Steel in Water Treatment Systems. https://3amakina.com/properties-and-uses-of-steel-and-stainless-steel-in-water-treatment-systems/
[3] Methods of wastewater purification from heavy metal ions (in Russian). https://www.vo-da.ru/articles/ochistka-ot-tyazholyh-metallov/metody-ochistki

In metalworking plants, various technological processes consume a substantial amount of water. Developing new or improved methods for extensive purification of this contaminated water is highly relevant from an environmental standpoint. Deep cleaning not only improves the surrounding area's ecology but can also help recover several heavy metals.

Currently, there are several methods used to clean wastewater with heavy metal ions, including precious non-ferrous metals. These methods, like electrochemical techniques, rely on the principles of physical chemistry, electrochemistry, and chemical technology. They mainly involve separation, transformation processes, and complex combined methods. Furthermore, the mechanism and speed of each stage are affected by numerous factors that are challenging to achieve simultaneously.

Calculation of vertical settling tanks and auxiliary structures

The work aims to extract valuable non-ferrous (and other) metals from the wastewater using the most commonly practiced reagent method. This method includes neutralization processes and redox reactions in which heavy metal ions are converted into hydroxide compounds and the resulting sludge is dewatered. If necessary, the pH value of the effluent is adjusted after purification[4,5] [19-21].

The article presents a generalized method for calculating vertical settling tanks for reagent settling, which can be used to remove all types of heavy metal salts. The choice of reagent settling in vertical settling tanks is justified by the relatively small quantities of these industrial wastewater. Settling tanks are particularly well-suited for extracting iron from industrial effluents, given that iron is the Earth's fourth most abundant chemical element (4.5-5%). It's important to note that in most iron-containing industrial effluents, the pH exceeds 8.3, leading to the prevalence of Fe^{3+} in the water over Fe^{2+}.

The efficiency of extracting insoluble Fe^{3+} as precipitated flocs of $Fe(OH)_3$ can be improved by pre-aerating the effluent. For this purpose, a pre-aerator can be designed as a separate unit, integrated, or attached to the vertical settling tank. To accurately calculate the selected vertical settling tanks, initial calculations of all equipment involved in the averaging and neutralization of these effluents need to be conducted [22-24].

The calculation is carried out in the following order:

1. Calculation of the reagents used,
2. Calculation of reagent facilities,
3. Calculation of solution tanks,
4. Calculation of settling tanks.

In our previous section, we outlined the formulas that result from the interactions between various reagents and acids (Table 1), as well as the formulas that arise from the interactions between reagents and heavy metal salts. We also took into account the molecular masses of the substances involved in these reactions (Table 2). The following sequential calculation approach is universal and allows for the calculation of the consumption of the specific reagent used for purification from specific salts of heavy metals. Since the flow of industrial wastewater usually varies over shifts (sometimes even within quite large limits), together with the neutralization installation, a built-in averager was also provided (Fig.1).

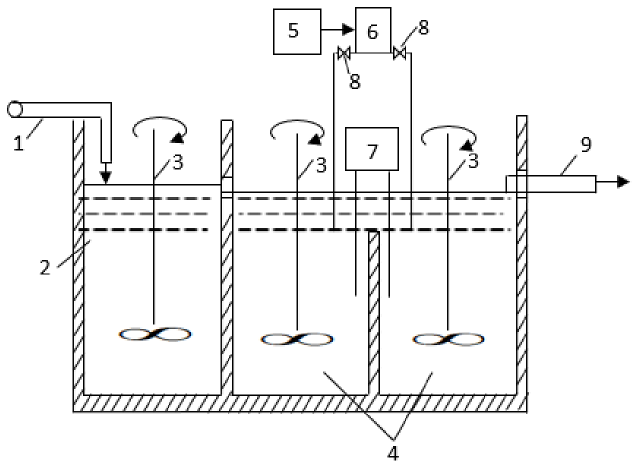

Fig. 1. *Scheme of the installation for averaging structure blending plant and wastewater neutralization*

1. acidic waste supply, 2. low-equalization basin, 3. mixer with mechanical drive, 4. neutralization chamber, 5. dispensable alkaline solution tank, 6. dispenser, 7. regulating pH meter, 8. valve, 9. neutralized drain into settling tank, 10. hole, ensuring the flow into the neutralization chamber

[4] Modern methods of water purification from heavy metals (in Russian). http://elib.bsut.by/bitstream/handle/123456789/6112

[5] Removal of heavy metals from water (in Russian). https://www.ecoindustry.ru/user/skruber/blogview/2053.html

Industrial acid wastes, through pipeline (1) enter the averaging chamber (2), where they are mixed with a stirrer (3) and through hole (10) enter the neutralization chambers. (4). At the same time, the alkaline solution from the supply tank flows into the dispenser (6) and, with open valves (8), is sent to the neutralization chambers. There, with the lowered indicators, the indicator of active hydrogen ions is regulated by the provided pH meter (7). Next, the neutralized wastewater is sent to the settling tank through pipeline (9). Note that mixer with mechanical drives are also used in the wastewater neutralization process.

Table 1. Molecular masses of the most frequently occurring salts of heavy metals in industrial wastewater

Name of heavy metals salts	Chemical formulas of heavy metal salts / molecular masses	Chemical records of metals / molecular masses
Iron sulfate	$FeSO_4$/152	Fe/56
Iron sulfate	$Fe_2(SO_4)_3$/400	Fe/56
Nickel (II) sulfate Nickel(II) chloride	$NiSO_4$/155 $NiCl_2$/130	Ni/59
Copper sulfate Copper (II) chloride	$CuSO_4$/160 $CuCl_2$/135	Cu/64
Zinc sulfate Zinc chloride	$ZnSO_4$/161 $ZnCl_2$/136	Zn/65
Lead (II) chloride	$PbCl_2$/178	Pb/207
Tin(II) chloride	$SnCl_2$/190	Sn/119

Table 2. Reaction equations between various reagents and acids

CaO	$H_2SO_4 + CaO + H_2O = CaSO_4 + 2H_2O$ 98 56 18 136 36 $2HCl + CaO + H_2O = CaCl_2 + 2H_2O$ 73 56 18 111 36 $2HNO_3 + CaO + H_2O = Ca(NO_3)_2 + 2H_2O$ 126 56 18 164 36 $2H_3PO_4 + 3CaO + 3H_2O = Ca_3(PO_4)_2 + 6H_2O$ 196 168 54 310 108
$Ca(OH)_2$	$H_2SO_4 + Ca(OH)_2 = CaSO_4 + 2H_2O$ 98 74 136 36 $2HCl + Ca(OH)_2 = CaCl_2 + 2H_2O$ 73 74 111 36 $2HNO_3 + Ca(OH)_2 = Ca(NO_3)_2 + 2H_2O$ 126 74 164 36 $2H_3PO_4 + 3Ca(OH)_2 = Ca_3(PO_4)_2 + 6H_2O$ 196 222 310 108
Na_2CO_3	$H_2SO_4 + Na_2CO_3 = Na_2SO_4 + H_2O + CO_2\uparrow$ $2HCl + Na_2CO_3 = 2NaCl + H_2O + CO_2\uparrow$ $2HNO_3 + Na_2CO_3 = 2NaNO_3 + H_2O + CO_2\uparrow$ $2H_3PO_4 + 3Na_2CO_3 = 2Na_3PO_4 + 3H_2O + 3CO_2\uparrow$
$MgCO_3$	$H_2SO_4 + MgCO_3 = MgSO_4 + H_2O + CO_2\uparrow$ $2HCl + MgCO_3 = MgCl_2 + H_2O + CO_2\uparrow$ $HNO_3 + MgCO_3 = Mg(NO_3)_2 + H_2O + CO_2\uparrow$ $2H_3PO_4 + 3MgCO_3 = Mg_3(PO_4)_2 + 3H_2O + 3CO_2\uparrow$
$CaCO_3$	$H_2SO_4 + CaCO_3 = CaSO_4 + H_2O + CO_2\uparrow$ $2HCl + CaCO_3 = CaCl_2 + H_2O + CO_2\uparrow$ $2HNO_3 + CaCO_3 = Ca(NO_3)_2 + H_2O + CO_2\uparrow$ $2H_3PO_4 + 3CaCO_3 = Ca_3(PO_4)_2 + 3H_2O + 3CO_2\uparrow$
Dolomite $CaCO_3{\cdot}MgCO_3$	$2H_2SO_4 + CaCO_3{\cdot}MgCO_3 = CaSO_4 + MgSO_4 + 2H_2O + 2CO_2\uparrow$ $4HCl + CaCO_3{\cdot}MgCO_3 = CaCl_2 + MgCl_2 + 2H_2O + 2CO_2\uparrow$ $4HNO_3 + CaCO_3{\cdot}MgCO_3 = Ca(NO_3)_2 + Mg(NO_3)_2 + 2H_2O + 2CO_2\uparrow$ $4H_3PO_4 + 3CaCO_3{\cdot}MgCO_3 = Ca_3(PO_4)_2 + Mg_3(PO_4)_2 + 6H_2O + 6CO_2\uparrow$

Note: In reactions with slaked lime and quicklime, molecular masses are also given.

Table 3. Reaction equations between various reagents and metal salts

CaO	$FeSO_4$+CaO +H_2O = $Fe(OH)_2$ ↓+$CaSO_4$ $ZnSO_4$+CaO +H_2O = $Zn(OH)_2$↓ +$CaSO_4$ $CuCl_2$ +CaO + H_2O = $Cu(OH)_2$↓ +$CaCl_2$ $NiCl_2$+CaO +H_2O =$Ni(OH)_2$↓ +$CaCl_2$ $Fe_2(SO_4)_3$ +3CaO +3H_2O =2$Fe(OH)_3$↓ +3$CaSO_4$ $NiSO_4$+CaO+H_2O =$Ni(OH)_2$↓ +$CaSO_4$ $ZnCl_2$ +CaO + H_2O = $Zn(OH)_2$↓+$CaCl_2$ $CuSO_4$+CaO +H_2O =$Cu(OH)_2$↓ +$CaSO_4$ $SnCl_2$ +CaO + H_2O = $Sn(OH)_2$ ↓+$CaCl_2$ $PbCl_2$ +CaO + H_2O = $Pb(OH)_2$↓ +$CaCl_2$
$Ca(OH)_2$	$FeSO_4$+$Ca(OH)_2$ =$Fe(OH)_2$↓ +$CaSO_4$ $ZnSO_4$+$Ca(OH)_2$ =$Zn(OH)_2$↓ +$CaSO_4$ $CuCl_2$ + $Ca(OH)_2$ = $Cu(OH)_2$↓ +$CaCl_2$ $NiCl_2$+ $Ca(OH)_2$ =$Ni(OH)_2$↓ +$CaCl_2$ $Fe_2(SO_4)_3$ +3$Ca(OH)_2$ =2$Fe(OH)_3$ ↓+3$CaSO_4$ $NiSO_4$+ $Ca(OH)_2$ =$Ni(OH)_2$↓ +$CaSO_4$ $ZnCl_2$ + $Ca(OH)_2$ = $Zn(OH)_2$↓+$CaCl_2$ $CuSO_4$+ $Ca(OH)_2$ =$Cu(OH)_2$↓ +$CaSO_4$ $SnCl_2$ + $Ca(OH)_2$ = $Sn(OH)_2$↓ +$CaCl_2$ $PbCl_2$ + $Ca(OH)_2$ = $Pb(OH)_2$↓ +$CaCl_2$
Na_2CO_3	$FeSO_4$+ Na_2CO_3 +H_2O =$Fe(OH)_2$↓ +Na_2SO_4 + CO_2↑ $ZnSO_4$+ Na_2CO_3 + H_2O = $Zn(OH)_2$ ↓+ Na_2SO_4 + CO_2↑ $CuCl_2$ + Na_2CO_3 + H_2O = $Cu(OH)_2$↓ + NaCl + CO_2↑ $NiCl_2$+ Na_2CO_3 + H_2O = $Ni(OH)_2$ ↓+ 2NaCl+ CO_2↑ $Fe_2(SO_4)_3$ + 2Na_2CO_3 + 3H_2O = $Fe(OH)_3$ ↓+3Na_2SO_4 + 3CO_2↑
Na_2CO_3	$NiSO_4$+ Na_2CO_3 + H_2O = $Ni(OH)_2$↓ + Na_2SO_4 + CO_2↑ $ZnCl_2$ + Na_2CO_3 + H_2O = $Zn(OH)_2$↓ + 2NaCl + CO_2↑ $CuSO_4$+ Na_2CO_3+ H_2O =$Cu(OH)_2$↓ + Na_2SO_4 + CO_2↑ $SnCl_2$ + Na_2CO_3+ H_2O = $Sn(OH)_2$ ↓+2NaCl + CO_2↑ $PbCl_2$ + Na_2CO_3+ H_2O = $Pb(OH)_2$ ↓+ NaCl + CO_2↑
$MgCO_3$	$FeSO_4$+ $MgCO_3$ +H_2O =$Fe(OH)_2$↓ +$MgSO_4$ + CO_2↑ $ZnSO_4$+ $MgCO_3$+H_2O =$Zn(OH)_2$ ↓+$MgSO_4$ + CO_2↑ $CuCl_2$ + $MgCO_3$ +H_2O = $Cu(OH)_2$ +$MgCl_2$↓ + CO_2↑ $NiCl_2$+ $MgCO_3$ +H_2O =$Ni(OH)_2$↓ +$MgCl_2$+ CO_2↑ $ZnCl_2$ + $MgCO_3$ + H_2O = $Zn(OH)_2$↓ + $MgCl_2$ + CO_2↑
$MgCO_3$	$FeSO_4$+ $MgCO_3$ +H_2O =$Fe(OH)_2$↓ +$MgSO_4$ + CO_2↑ $ZnSO_4$+ $MgCO_3$+H_2O =$Zn(OH)_2$↓ +$MgSO_4$ + CO_2↑ $CuCl_2$ + $MgCO_3$+ H_2O = $Cu(OH)_2$↓ +$MgCl_2$+ CO_2↑ $NiCl_2$+ $MgCO_3$ +H_2O =$Ni(OH)_2$↓ +$MgCl_2$+ CO_2↑ $ZnCl_2$ + $MgCO_3$ +H_2O = $Zn(OH)_2$ ↓+ $MgCl_2$+ CO_2↑
$CaCO_3$	$FeSO_4$+ $CaCO_3$ +H_2O =$Fe(OH)_2$↓ +$CaSO_4$ + CO_2↑ $ZnSO_4$+ $CaCO_3$+H_2O =$Zn(OH)_2$ ↓+$CaSO_4$ + CO_2↑ $CuCl_2$ + $CaCO_3$ + H_2O = $Cu(OH)_2$↓ + $CaCl_2$ + CO_2↑ $NiCl_2$ + $CaCO_3$ + H_2O = $Ni(OH)_2$ ↓+ $CaCl_2$ + CO_2↑ $Fe_2(SO_4)_3$ + 3$CaCO_3$ +3H_2O = 2$Fe(OH)_3$↓ + 3$CaSO_4$ + ↑3CO_2 $NiSO_4$+ $CaCO_3$ +H_2O =$Ni(OH)_2$↓ +$CaSO_4$+CO_2 ↑ $ZnCl_2$ + $CaCO_3$ + H_2O = $Zn(OH)_2$ ↓+$CaCl_2$ +CO_2↑ $CuSO_4$ + $CaCO_3$ + H_2O = $Cu(OH)_2$ ↓+ $CaSO_4$ +CO_2↑ $SnCl_2$ + $CaCO_3$ + H_2O = $Sn(OH)_2$ ↓+ $CaCl_2$ + CO_2↑ $PbCl_2$ + $CaCO_3$ + H_2O = $Pb(OH)_2$↓ +$CaCl_2$ +CO_2↑
Dolomite $CaCO_3 \cdot MgCO_3$	2$FeSO_4$ +$CaCO_3 \cdot MgCO_3$+H_2O =2$Fe(OH)_2$ ↓+$CaSO_4$ + $MgSO_4$ +2CO_2↑ 2$ZnSO_4$ + $CaCO_3 \cdot MgCO_3$+H_2O =2$Zn(OH)_2$ +$CaSO_4$ + $MgSO_4$ +2CO_2↑ 2$CuCl_2$ +$CaCO_3 \cdot MgCO_3$ = 2$Cu(OH)_2$↓ + $CaCl_2$ + $MgCl_2$+ 2CO_2↑ $NiCl_2$ + $CaCO_3 \cdot MgCO_3$ = $Ni(OH)_2$↓+ $CaCl_2$ + $MgCl_2$ + CO_2↑ $Fe_2(SO_4)_3$ + $CaCO_3 \cdot MgCO_3$ +6H_2O = 4$Fe(OH)_3$↓ + 3$CaSO_4$ + 3$MgSO_4$ + 6CO_2↑ 2$NiSO_4$+ $CaCO_3 \cdot MgCO_3$+2H_2O =2$Ni(OH)_2$↓ +$MgSO_4$ +$CaSO_4$+2CO_2 ↑ 2$ZnCl_2$ + $CaCO_3 \cdot MgCO_3$ +2H_2O = 2$Zn(OH)_2$↓ + $CaCl_2$+ $MgCl_2$+2CO_2↑ $CuSO_4$ + $CaCO_3 \cdot MgCO_3$ + 2H_2O = $Cu(OH)_2$↓+$CaSO_4$ + $MgSO_4$ + 2CO_2↑ 2$SnCl_2$ + $CaCO_3 \cdot MgCO_3$ + 2H_2O= $Sn(OH)_2$ ↓+ $CaCl_2$ + $MgCl_2$ +CO_2↑ 2$PbCl_2$ + $CaCO_3$ + $MgCO_3$ + 2H_2O = 2$Pb(OH)_2$↓ +$CaCl_2$ + $MgCl_2$ +2CO_2↑

Reagent consumption (G) is determined by the following formula:

$$G = K_r \cdot Q\left(\sum aA + \sum bB\right)\frac{100}{c}, \quad \frac{kg}{day}, \tag{1}$$

where $K_r = 1.1...1.3$ - reserve coefficient; Q - daily flow rate, m^3/day; A and B - respectively concentrations of acids and salts of heavy metals; $a = \frac{m}{n_a}$ - specific consumption of the reagent used for acid neutralization, kg/kg; m and n_a - the molecular masses of the reagent and acid, respectively; $b = m/n_m$ - specific consumption of the reagent used for the precipitation of heavy metal salts; n_m - molecular mass of heavy metal salts; $C = 40...70\%$ - content of the active substance in the reagent used.

The area of the reagent stock is determined by the following formula:

$$S = \left(Q \cdot ts\right)/h \cdot p, \ m^2, \tag{2}$$

where $ts = 30\,\text{min}$ - reserve time; $h = 1.5...2.0\,\text{m}$ - the height of the reagent layer, $\rho = \left(1...1.2\right)t/m^3$ - specific gravity of the reagent.

Having the surface, we select the dimensions of the storage (width and length).

The volume of supply tanks (W_t) is determined by the following equation:

$$W_t = \frac{G \cdot C}{n_s Z}, \quad m^3, \tag{3}$$

where $n_s = 4...6$ is the number of solutions obtained per day; $z = 4...6\%$ - solution content.

For the volume, we can select the number of tanks (at least two) and their dimensions. The consumption of the reagent solution is determined by the formula:

$$q_r = \frac{1000 \cdot n_s \cdot W_s}{86400} = \frac{n_s \cdot W_s}{86.4}, \quad l/\sec. \tag{4}$$

We also determine the total consumption of wastewater (q_t) and reagent solution by the following way:

$$q_t = q + q_r = \frac{Q_s}{86.4} + q_r, \ l/\sec. \tag{5}$$

Mixer volume (W_m) is determined by the formula:

$$W_m = \frac{60 \cdot q_t \cdot t_m}{1000} = \frac{q_t \cdot t_m}{16.7},$$

where $t_m = 5\,\text{min}$ is the mixing time.

For the volume, the diameter and height of the mixer are determined. Usually, we accept one mixer and its dimensions (diameter and height). The volume of the neutralization chamber is determined by the formula:

$$W_n = \frac{q_t \cdot 60 \cdot t_n}{1000} = \frac{q_t \cdot t_n}{16.7}, \ m, \tag{6}$$

where $t_n = 30$ min is the required time to neutralize the flow.

Taking two neutralization chambers, we get $W_1 = \frac{W_n}{2}$ and the sizes of each of them.

The calculation of settling tanks begins with determining their diameter (B) using the following formula:

$$D = \sqrt{\frac{4qt}{\pi \cdot Vn_{st.t.}}}, \ m. \tag{7}$$

where $V \leq 0.2$ mm/sec - the rate of wastewater in the settling tank; $n_{st.t.}$ – the number of settling tanks, which is advisable to take a multiple of 4, taking into account the fact that $D \leq 9.0$ m.

The height of the deposition zone is determined by the formula:

$$h_{set.} = 3.6 \cdot t_{st.}, \tag{8}$$

where $t_{st.} \geq 24$ is the duration of suspension deposition.

We determine the dry matter content (M) in the accumulated slag using the formula:

$$M = \left[K_s \cdot \frac{100 - C}{C} \left(X_1 + X_2 + X_3 + y_1 + y_2 - 2 \right) \right] \cdot Q, \quad kg / day, \tag{9}$$

where $X_1 = \sum a \cdot A$ - reagent consumption for the neutralization of acids contained in 1m^3 of wastewater, kg/m^3; $X_2 = \sum b \cdot B$ - reagent consumption for the precipitation of metal salts contained in 1m^3 of wastewater, kg/m^3; $X_3 = \sum \frac{m_h}{n_m} \cdot B$ - the amount of hydroxyls that are formed from the metals contained in 1m^3 of wastewater (m_h is the molecular mass of hydroxyls); $Y_1 = \sum \frac{m_s}{n_a} \cdot A$ - the amount of insoluble salts formed during the acid neutralization, kg/m^3; n_s - the molecular mass of insoluble salts; $y_z = \sum \frac{m_s}{n_m} \cdot B$ - the amount of salts formed during reactions between reagents and salts of heavy metal, kg/m^3; z – solubility of calcium sulfate ($CaSO_4$) in water. If $y_1 + y_2 - 2 < 0$, then the negative value of the expression is neglected.

We determine the volume of sludge (W_{sl}) using the formula:

$$W_{sl} = \frac{M}{10(100 - p)}, \quad m^3 / day, \tag{10}$$

where $p = 86...88\%$ is the moisture of the sludge.

We determine the settling tank conical part volume using the formula:

$$W_C = \pi \cdot D^3 / 24, \; m^3. \tag{11}$$

Taking the angle of inclination of the settling tank conical section to be 45^0, we obtain the height of the conical part – $h_{c.q.1} = D/2$.

We determine the settling tank cylindrical part volume (W_C) using the formula:

$$W_C = \frac{W_{sl}}{n_q + 1} - W_c, \; \text{m}^3, \tag{12}$$

where $n_q \geq 2$ is the estimated number of settling tanks.

We can also determine the height of the cylindrical part using the formula:

$$h_c = \frac{4 \cdot W_C}{\pi D^2}, \; \text{m}. \tag{13}$$

Taking the height of the neutral part $h_1 = 0.25$ m, we determine the depth of the settling tank (H):

$$H = h_w + h_c + h_{con} + h_1, \; \text{m}, \tag{14}$$

where $h_W = 0.5$ m is the height of the side wall from the drainage level.

The diameter of the central part of the vertical settling tank (Fig.2) is determined by the equation:

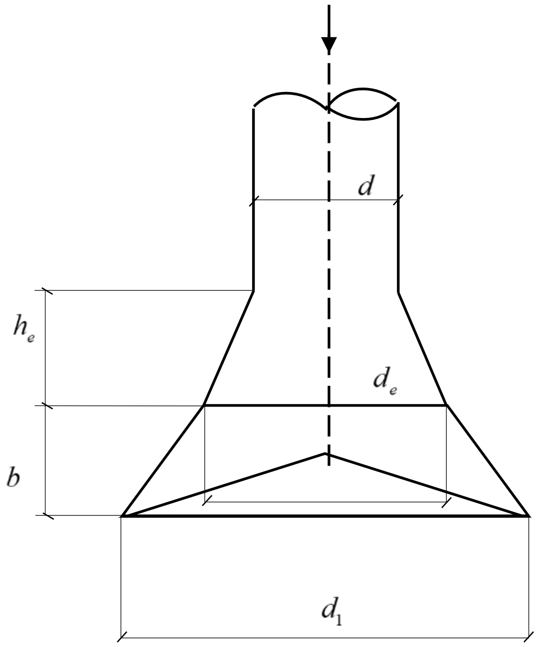

Fig. 2. *The central part of the supply pipe of a vertical settling tank*

$$\frac{Q}{3.6 \cdot W_c} = n_r \cdot \frac{\pi d^2}{4}, \tag{15}$$

where Q - wastewater consumption, m^3/day,

n_r - the estimated number of settling tanks.

The diameter of the central pipe in mm is determined from equation (16):

$$d = \sqrt{\frac{4Q \cdot 1000}{\pi \cdot n_c \cdot V_c \cdot 86400}}, \text{ mm.} \tag{16}$$

where $V = 30$ mm/sec - flow rate in the central pipe.

We also determine the length of the transition part of the central pipe (h_e) and its diameter (d_e) according to the condition $d_e = h_e = 1.35 \cdot d$, mm.

The diameter of the central pipe (d_1) is determined by the following formula:

$$d_1 = 1.3 \cdot d_e, \text{mm.} \tag{17}$$

After, we determine the length of the central pipe inserted-joint part using the formula:

$$\frac{Q}{3.6 \cdot V_s \cdot V_{s.p.p.}} = \pi \cdot n_c \cdot d_e \cdot b, \tag{18}$$

where $V_{s.p.p.} = 20$ mm/sec is the wastewater velocity at the splashing plate.

Taking into account the need for identical measurements of units, from equations (18) we get:

$$b = \frac{1000 \cdot 1000 \cdot Q}{864000 \cdot \pi \cdot n_c \cdot V_{s.p.p.}}, \text{ m.} \tag{19}$$

Conclusion

1. We have provided the necessary neutralizing reagents and all the appropriate equipment to neutralize industrial metal-containing wastewater, which can have an alkaline or, most often, acidic medium, during the treatment process.
2. A homogenizer is built into the neutralization chambers to reduce capital investments, simplify operations, and ensure accurate calculation of treatment facilities.
3. The suggested method allows for a detailed calculation of the vertical settling tank when removing various metal salts from acidic wastewater using specific reagents.
4. If necessary, wastewater that has been clarified in settling tanks can also undergo further purification, preferably through sand or dual-layer filtration. In all cases, a disinfection process is also planned after the purification process.
5. The sludge accumulated in the conical section of the settling tank can be transferred to sludge pads for dehydration and further extraction of valuable metals.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

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HISTORICAL MEMORY AND VOLUMETRIC-SPATIAL COMPOSITION OF TSITSERNAKABERD MEMORIAL COMPLEX

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Abstract: *The erection of memorials and monuments plays an important role in the historical memory of humanity, self-recognition of society and awareness of the social nature of memory. From this point of view, we looked at the architectural-spatial environment of Tsitsernakaberd, the memorial complex dedicated to the victims of the Genocide, the organization of which is subject to the perpetuation of historical memory and is one of the manifestations of the preservation of national identity. It finds its parallels in world practice. The motivation for the construction of the memorial complex was the fiftieth anniversary of Yeghern. The Tsitsernakaberd hill has been completely culturalized, the landscape has passed through four conceptual lenses: "text", "arena", "performance" and "wound", achieving the harmony of hand-made and non-handmade. In the work, a complete examination of the architecture of the memorial complex was carried out by the method of comparative analysis of professional literature and personal observations. In conclusion, it can be said that the memorial dedicated to the memory of the Genocide victims, apart from its historical and artistic significance, is also a universal value and a sacred place for all those who consider human life as an absolute value regardless of nationality, religion or race.*

Keywords: *ethnic, memory, memorial, architecture, metaphor, monument, ideological, artistic, historical.*

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Received: 10.07.2024
Revised: 05.08.2024
Accepted: 28.08.2024

Introduction

The history of humanity is the story of the philosophical space-time connection of the Trinity of past, present and future. Throughout history, the concept of memory has been important, as it links this chain of unity. Memorial complexes have been created since time immemorial and preserve their traditionality till now as a materialized manifestation of human memory [1]. Memorial complexes play an important role in increasing the social awareness of collective memory, thus even today they are still being built in various forms [2].

However, since the late 19th century to the present, changes in the architectural composition of memorial complexes have altered the relationship between visitors and memorial complexes. Until the 19th century, monuments were simply built to perpetuate the memory of individuals or heroes, representing pictorial objects inaccessible and visible from afar, modern memorial complexes, on the other hand, allow the user to be widely involved in the memorial acts by touching, listening and participating [3]. Memorial complexes do not merely reflect ideas about the past, but confirm and insure the past. Becoming widespread around the world is, to some extent, a reference to the present, current political situations and circumstances, as collective memory is anchored in the present. Memorial complexes are part of the socio-political process which show how people value, discuss or heal historical wounds [4]. They also provide a sense of belonging and ownership among citizens, enhancing the touristic, economic and cultural value of the area.

The problem and the multilayered aspects of studying the structural features of memory have regularly been and are being touched upon by a number of scholars from all over the world [5]. As for the policy of commemorating the victims of the Great Genocide it has been addressed by Armenian scholars such as

Harutyun Marutyan, Karen Balyan and Levon Abrahamyan [6-8], considering the memory of the Armenian Genocide as one of the current pillars of the Armenian identity.

The Armenian Genocide has long gone beyond the position of being a purely Armenian tragedy and has entered the realm of world history. Certainly, the role of the Memorial Complex in this case was tremendous.

According to Harutyun Marutyan, "Memory and especially historical memory are among the most important elements that define the terms "ethnic community (ethnic)", "nation" and "national identity" [6].

The above-mentioned authors referred to the idea of memory, the genocide and the memorial separately. Some authors approached this question more superficially [9]. Therefore, this work is an attempt to present these three ideas on one plane, in a comprehensive way. Therefore, the aim of the research is to analyze the spatially organized materialized environment of the Genocide Memorial Complex, connecting it with the historical memory, as well as emphasizing the role of the landscape of the Memorial Complex and architectural composition in the application of architectural landscape elements in the urban area and the importance of realizing the user's sensory experience in the memorial space.

Methods and Materials

In the work, a complex examination of the memorial complex was performed, which was carried out by the method of comparative analysis of professional literature and personal observations. Archival documents and photographs were also used, which made it possible to restore important episodes related to the historical period of the Yeghern Memorial and the motivations for its construction.

Given the fact that the role of monuments and memorial complexes is great in historical memory, the self-recognition of society and the awareness of the social nature of remembrance, a number of scholars around the world now show a growing interest in memorial complexes and what the influence of construction, interpretation and disputability of a place or area in this process is.

From this point of view we have observed and studied the architectural-spatial environment of the Tsitsernakaberd Memorial Complex dedicated to the victims of the Genocide. The organization of the Memorial is subject to the perpetuation of historical memory, which greatly helps the nation to preserve the national identity created in the fusion of common experience and centuries-old culture.

The motivation for building the Memorial Complex was the fiftieth anniversary of the Genocide. And this Complex is the living expression and materialization of these fifty and more years of condensed terrible feelings and indomitable faith, which has gone beyond its historical and artistic significance and has become a holy place for all Armenians, and why not, for foreigners, for whom human life is an absolute value regardless of nationality, religion or race.

Armenian architects achieved all this as a result of deep analysis and long discussions, connecting the world classical experience with their national heritage. By studying the landscape through four conceptual lenses, which are "text", "arena", "performance" and "wound", they achieved a perfect harmony of the environment, and the entire Hill was culturalized.

From the foot of the Tsitsernakaberd Hill, the commemoration road rises to the ideological culmination, where the Memorial Complex erects. It is a set of three large monuments bearing theological significance: the memorial wall, the temple of eternity with the unquenchable fire in the center, and the memorial column.

In this paper, a complete examination of the Memorial Complex has been carried out by means of a comparative analysis of professional literature and personal observations.

From Memory to Memorial Complex

Since time immemorial, people have realized that nations or tribes simply cannot exist without memory, remembrance or ethnic memory. Consequently, megaliths, tombs and memorial columns like obelisks were built to materialize historical memory, which is the basis of national identity.

The great philosopher [10] perceives memory in a completely different way other than sensation or perception. Without the eye we cannot have the sensation of "blue", but through the eye we still do not have the memory of "blue" at all. For the eye now to give us that sensation, some blue object must appear in front of it. Architecture, or in this case, memorial complexes, serve as that "blue object" for the user. The perception brought to life by memory is considered to be new and in no case the preserved old one. A memory is something that can be re-imagined, and it does not mean that the imagination can become alive once again. Something that appears once again is different from the imagination itself. "I remember"- means I am experiencing something once again that no longer exists. I connect the experience of the past with my present life. This refers to every memory. So, of course, no feeling is wasted, as the soul preserves it as a memory, while the spirit draws from it whatever can enhance its abilities and its bio content.

If the spirit stores the intangible treasures or more precisely the intangible culture, the architecture transforms the intangible culture into an already visible, tangible, material culture, filled with the ideology, aspirations and heroism of the national spirit. Here already physical parameters, types of feelings, and social goals are combined in memorial complexes, making the memory of war or atrocity a part of public life, a celebration of the past or a commemoration of the past. The forms of significance of memorial complexes are influenced by reinterpretations of political history that reinforce, contradict or emphasize the status of the past events.

Results and Discussion

The Term Genocide and the Motivation to Build the Memorial Complex

The Genocide was the state policy of mass deportation and extermination of the Armenian population in Western Armenia, Cilicia and other Armenian-inhabited areas of the empire, as well as in Eastern Armenia, of the Ottoman Empire and the Kemal government during the First World War (1914-18) and the following years. It is characterized as the first genocide of the 20th century. This was an unprecedented tragedy that happened to Armenians. This undeniable fact is stubbornly not accepted by the Turkish government. Following the latter, many states of the world keep their eyes closed against the reality.

The term Genocide was defined and popularized in 1944 by a Polish lawyer of Jewish origin, Professor Raphael Lemkin. The Armenian Genocide carried out by Ottoman Turkey in 1915 also corresponds to this definition. According to Lemkin, Genocide is not only the physical annihilation and elimination of a national or religious group, but also the destruction of its national-spiritual culture. It is worth mentioning that this Genocide continues up to now. In the territories occupied by Azerbaijan, many memorial complexes are being physically destroyed and desecrated with the aim of destroying the collective and historical memory of the ethnic group (memorial complexes dedicated to those who died in World War II and Artsakh War I in Talish Village of the Republic of Artsakh)[1].

Rituals, customs, myths, shared historical memories and traditions are ways and actions to bind members of a nation and define their relationships. And since our national understanding of the past is always a tool for solving current problems, it was important to present the collective memory in the form of a monumental structure [11], which was implemented in the case of the Tsitsernakaberd Memorial Complex.

The motivation for building the Memorial Complex was the half-century anniversary, when people were powerless to bear the silence and indifference of others. And it was an absolutely spontaneous demand and eruption of ethnic memory.

The Genocide has never been forgotten, but for many years it has outwardly been silenced. This was conditioned by the fact that the spread of any national ideology was prohibited in the Soviet Union. However, on the eve of the 50th anniversary of the Genocide, the entire Armenian nation, especially the youth, as well as the Government of the Republic were preparing for that sad anniversary.

[1] https://monumentwatch.org/.

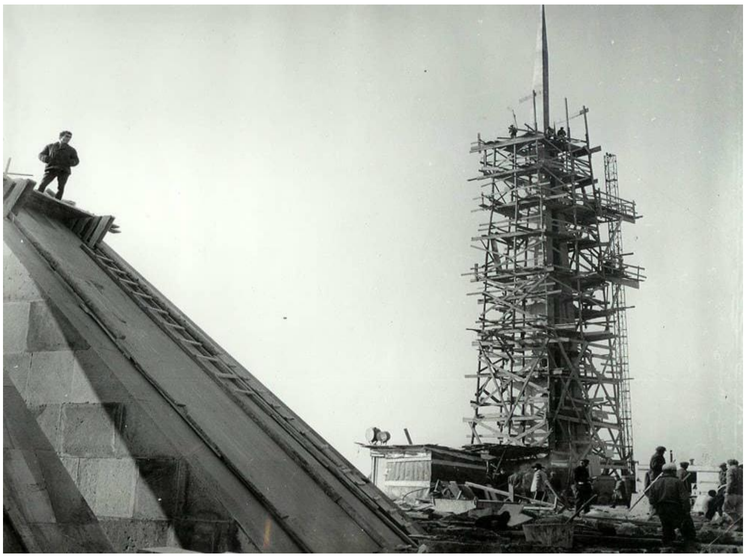

Fig. 1. *The Construction process of the Tsitsernakabert Memorial*

Fig. 2. *First Secretary of the Central Committee of the Communist Party of Armenia (CPA) Anton Qochimyan lights the unquenchable fire of the memorial*

On December 13, 1964, the 1st Secretary of the Central Committee of the CPA Ya. Zarubyan sent a letter of justification to the Central Committee of the Communist Party of the Soviet Union on officially celebrating the 50th anniversary of the Genocide, with the list of envisaged events. Based on the Decree of the Council of Ministers of the Armenian SSR dated March 16, 1965, the program and conditions of the republican tender for the construction of the monument commemorating the victims of the Great Genocide were published in the newspapers. On April 24 of the same year, a solemn meeting was held at the Yerevan Opera House, during which the beginning of the competition was officially announced. 78 projects were submitted to the Competition. A prestigious committee consisting of 12 people chose the project with the code "Flag of the USSR", the authors of which were A. Tarkhanyan and S. Kalashyan. 776.800 rubles were allocated for the construction, and "Yerkimshin" trust was chosen as the contractor. Initially, the official opening ceremony of the Memorial Complex was envisaged on April 24, 1967, but was later changed on November 29, the day of Sovietization of Armenia (Figs. 1,2).

The Volumetric-Spatial Composition of the Memorial Complex

After all, what is Architecture?

To enclose a part of space within certain boundaries. To give body, form and life to that space. To convey to it our physical and spiritual movement. Also to surrender to it and participate in the life of the Whole through a balanced, unobtrusive and harmonious structure. To be one and live a complete, full life with structure. When the structure, symbolizing us, is weight and symmetry, our consciousness is no longer blurred, it returns to its center, national self-awareness and ethnic memory, then it spreads and radiates. The free movement of the body, unfettered breathing and mental satisfaction are the three impulses that form true architecture [12].

Here, with the Tsitsernakaberd Memorial Complex, our architects found the body, form and life that should express and preserve the historical destiny of the nation.

According to the researchers, the construction of the memorial complex, which essentially meant recognition of the fact of genocide by the Soviet government, should at the same time extinguish the wave of the national movement in Armenia. Therefore, the monument symbolizing the genocide could not be located in the center of Yerevan, near the main square or the opera, in order to avoid mass visits. Therefore, the

Tsitsernakaberd hill was chosen for the construction of the memorial, in a remote, undeveloped, very inaccessible place in Yerevan.

Tsitsernakaberd Hill is located on the right bank of the Hrazdan River-in the western part of the capital and has an area of 132 hectares. After planting trees, it turned into a park, and was chosen as the site for the Memorial Complex. Studies show that the measurement of physical elements and the user's sensory experience are best taken into account when designing the Memorial landscape. It is ideal for the commemoration and the space provided. Simpler forms of the composition and symbolic messages allow users to more easily interact and understand the concept and purpose of the Memorial Complex.

Tsitsernakaberd Hill has been completely culturalized, the landscape has passed through four conceptual lenses [13,14], as is usually or traditionally done in the case of memorials: "text", "arena", "performance" and "wound", reaching the harmony between anthropogenic and naturogenic.

From the foot of the Tsitsernakaberd Hill, the commemoration road rises to the ideological culmination, where the Memorial Complex erects. Along this entire road, radio receivers are placed that play spiritual or national music (especially on Memorial Day), as if to commemorate the innocent victims. And this "liturgy" immediately cuts off the visitors from the busy daily life of the city, allowing them to immerse themselves into the arms of history, to awaken the ethnic memory, to review their present and, why not, not to get bored after a rather long ascent. Similar elements in memorial complexes (water, color, music, plants, scents, furniture, fire) are tools that architects use to create certain sensory impressions in memorial complexes [3]. We can consider this as the first successful element that guides visitors inside the Memorial Complex.

Inside is the Memorial Complex which erects as a set of monuments with three major theological meanings: the memorial wall, the temple of eternity with the unquenchable fire in the center, and the memorial column (Fig.3).

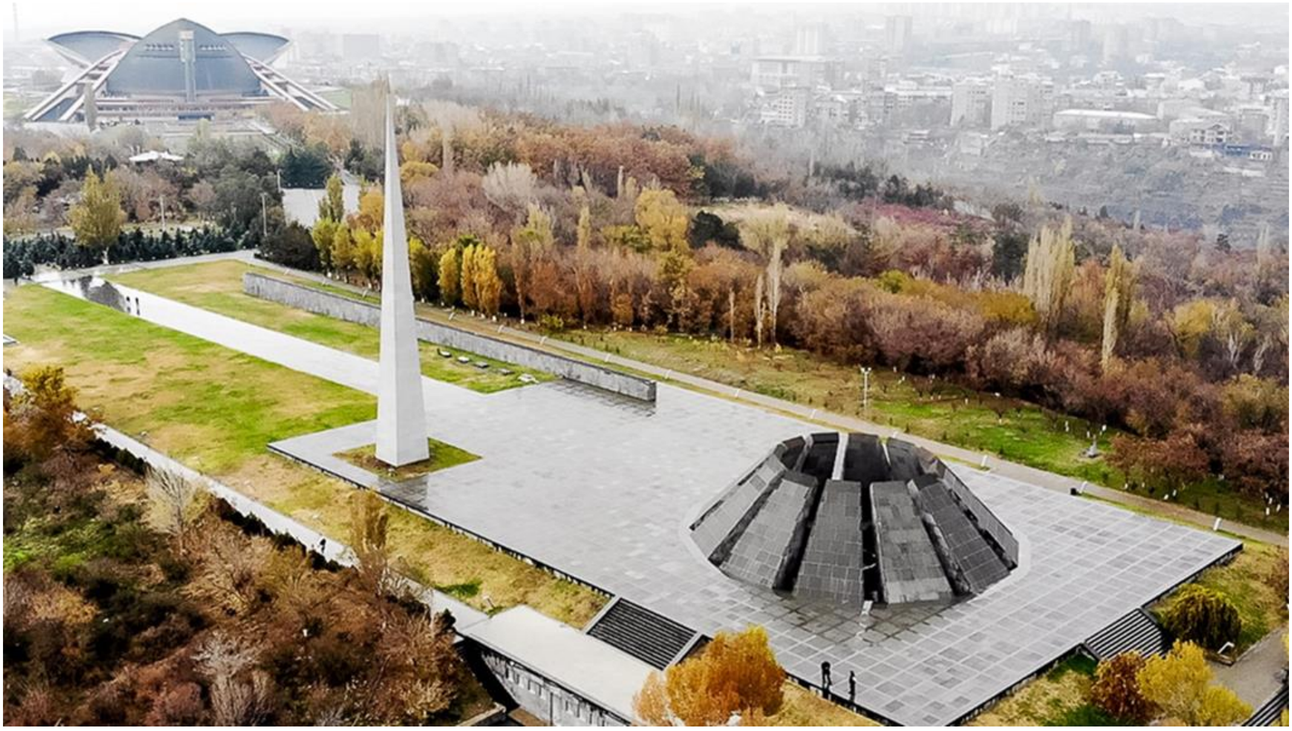

Fig. 3. *General view of the Memorial from the South*

The names of the locations, where the atrocities took place, are engraved on the hundred-meter-long memorial wall. This text metaphor symbolizes the ratification for historical events. Since 1996, the jars of soil taken from the graves of those who raised the voice of protest against the Armenian Genocide have been buried on the opposite side (Fig.4).

Fig. 4. *The wall where the names of the main towns affected by the Armenian genocide are engraved*

Fig. 5. *Twelve slabs grouped in a circle protecting, 1.5 meters deep, the "eternal flame", a sign of mourning*

The Memorial Hall is located in the performance metaphor: the 12 basalt chamfered pylons bowed to the unquenchable fire, forming a cone-shaped structure with an open volume, symbolize the tomb of the victims of the Great Genocide, where the ritual ceremonies are performed, and the unquenchable fire located in the center is the expression of the "unhealed wound".

The Temple of Eternity consists of 12 stone slabs. The number 12 is chosen based on geometrical laws, however the people consider that these columns symbolize the 12 largest states in Western Armenia (Fig.5).

In the arena metaphor, the 40-meter memorial column rising to the sky is a symbol of the national revival of the Armenian people (Fig.6).

The Armenian Genocide Museum-Institute[2,3,4]

The museum building summarizes the organization and ideological integrity of the spatial environment. Apart from museum-related functions, it also seems to museumize historical memory with documents (Fig.7).

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[2] Armenian Genocide Museum-Institute. Activity, Yerevan. http://www.genocide-museum.am/arm/structure.php

[3] Armenian Genocide Museum-Institute. Genocide, Yerevan. http://www.genocide-museum.am/arm/genocide.php

[4] Armenian Genocide, Yerevan (in Armenian). https://hy.wikipedia.org/wiki/%

Fig. 6. *The erect monument symbolizes rebirth*

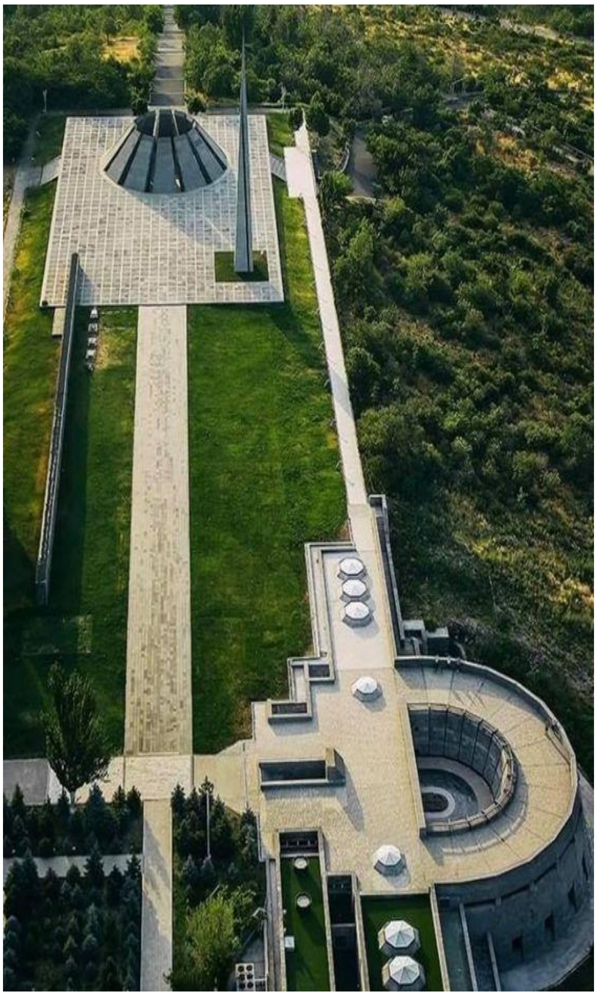

Fig. 7. *The Armenian Genocide Museum-Institute*

This scientific-cultural institution is located in the southwestern part of the Memorial Complex and occupies an area of 2000 square meters. It has an inner courtyard, the words of witnesses of the first Genocide of the 20th century are engraved on the 12 faces of the basalt wall. Among them are Henry Morgenthau, Fritjof Nansen, Anatole France, Jacques de Morgan, Valery Brusov and others. The map of Western Armenia with an area of 45 square meters was carved on the wall of the Hall, on which the places of massacre and displacements are marked. In 1995-2013, the exhibition materials were presented in the 3 halls of the Museum, mainly in the form of documents, copies of photo documents, ancient press and literature dedicated to the Hamidian massacres, the immolation of Adana and the Armenian Genocide. The Museum has a cinema hall, a scientific library, archival funds and offices (Figs. 8,9).

Fig. 8. *Inside the museum*

Compared to the Monument, the propaganda value of the Museum is incomparably greater [15].

Such sensitive sites have also become pivotal for diplomacy between friendly countries, mostly in the form of state visits that include promises that such atrocities will never happen again [16].

Fig. 9. *Display in the information centre*

Conclusion

In this research, an attempt was made to show how a properly organized architectural volume-spatial composition can best contribute to the preservation, strengthening and perpetuation of collective memory. And one of the important prerequisites for the survival of the nation is the collective memory.

Having subjected the component parts of the memorial to a deep analysis, we have come to the following conclusions:

1. The examination of the Yeghern monument complex clearly reveals the ideological content of the ensemble and the interconnectedness of form-creating elements.
2. The area has been completely culturalized.
3. In accordance with the classical traditions of Armenian architecture, the unity of hand-made and non-hand-made is noticeable.
4. Yeghern Memorial stands as a stone witness of historical memory in the spatial support of Yerevan and has become one of the symbols of the city.

Thus, the results of the work can be useful for researching and raising new, heroic, constructive memories within the framework of both architectural heritage and modern architecture.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

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GREEN ROOF RETROFITTING IN ALGERIA BETWEEN SUSTAINABILITY AND SEISMIC VULNERABILITY

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Abstract: *Installing green roofs in urban areas is a sustainable practice towards the ecological transition, they offer many advantages with regards to reducing energy consumption, mitigating the urban heat island effect, managing runoff ...etc. In order to propagate this technique, green roofs have to be installed on the top of existing buildings, which can increase their vulnerability during seismic events. The present paper aims to evaluate the impact of green roof retrofitting on the seismic performance of a collective housing in Algeria. To this end, the finite element method was adopted to investigate the seismic-related parameters according to the Algerian seismic regulations. The studied reinforced concrete building is located in the district of Constantine (northern east of Algeria). It was found that the presence of concrete walls, recommended by the Algerian seismic regulations, increases the rigidity of the building, which reflects positively on the building's natural period and displacements. As for the stress-related parameters, the reduced normal force does not increase much; however, a significant increase in the shear forces at the base due to green roof implementation was observed. It was also found that adding a green roof contributes more to the stabilizing moment than to the overturning one during an earthquake event. Hence, in the studied context, the presence of load-bearing concrete walls offers certain positive effects on green roof installation with regard to the seismic performance. Nevertheless, a thorough seismic investigation should be performed before installing green roofs on the top of existing collective housing in Algeria.*

Keywords: *green roof, seismic performance, finite element, ecological transition.*

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Received: 07.08.2024
Revised: 01.09.2024
Accepted: 12.09.2024

Introduction

Climate change effects raise concerns about improving and protecting the environment, especially in urban areas. Innovative eco-friendly practices, like green roofs [1-3], are a key tool towards achieving an ecologically functional land cover in cities. As a planning strategy to face the climate challenges in urban centers by improving the environment quality, green roofs implementation is an important green technology that hosts vegetation in a specially designed substrate [4,5]. The history of green roofs in many cultures goes back thousands of years ago [6]. However, the appearance of the modern concept of green roofs took place in the 20th century, adopted in construction in Germany, and then in Northern Europe, North America, and other Asian countries [7]. Over the past decades, extensive green roofs have been considered as a valuable tool for sustainable development [8]. The environmental and economic benefits due to the thermal regulation capacity of green roofs have resulted in accelerating research and practice of this technique [8,9]. Green roofs offer other advantages for sustainable buildings and cities, including: improving air quality, mitigating the urban heat island effect, managing stormwater (by retaining and then slowly releasing rainwater), preserving the ecological environment, improving sound insulation ... etc. [10-13].

In the Mediterranean region, green roofs are considered as a useful technique for sustainable urban stormwater management, as they compensate for man-made impervious surfaces by absorbing a certain amount of rainwater and slowly releasing the rest into the evacuation systems [14]. In summer, in the

Mediterranean region, green roofs improve energy efficiency and mitigate the urban heat island effect, which consequently reduces the environmental impacts [15]. Weather and vegetation types control the performance of green roofs [16]. The installation of green roofs is gaining more popularity for microclimate regulation, as they are closely associated with climate and the environment [17]. For the specific climatic conditions in the Mediterranean region, the installation of green roofs is a complicated operation as it faces many challenges, such as selecting appropriate vegetation, and designing for climate change [18]. Therefore, plant breeding and improved growing substrates are crucial in future green roof research [19]. The presence of grass on the roofs of buildings could potentiate the effect of trees and shrubs. On the other hand, species with greater sizes and biomass perform better in reducing water runoff, compared to species with smaller sizes and lower biomass [20, 21]. In order to promote biodiversity, green roofs should include different types of substrates, which allows for the creation of multiple microhabitats, which can eventually support a larger diversity of species than if they were uniform [22].

Algeria, like other northern African and Mediterranean countries, is facing many environmental challenges, such as desertification, drought, biodiversity loss, air and water pollution …etc. [23]. Although the installation of green roofs in Algeria is not yet widespread, there is a growing interest in this green practice in the country. The work of [24] reports that the implementation of green roofs and facades could transform the Saharan cities in the southern part of the country into an ecological urban environment. In another study carried out in the town of Jijel, in the northern east of Algeria, the results show that green roofs can be an efficient technique for improving the thermal performance of the surrounding microclimate, and also the energy performance of buildings in urban areas [25].

Green roofs offer great advantages when it comes to reducing urban heat island, regulating runoff, and enhancing the overall life quality...etc. However, in order to propagate its use, green roofs have to be installed on existing buildings, which raises concerns about its impact on the building structure. In regions where earthquakes are frequent, the vulnerability of a building when adding a green roof on the top is crucial. In literature, few authors have worked on the seismic behavior of buildings with green roofs [26-31]. However, in the seismic context of Algeria, and the Algerian seismic regulations, the impact of green roof retrofitting on the seismic performance of buildings was not tackled yet.

The present paper shed light for the first time on the seismic impact of green roofs retrofitting on collective housing according to the Algerian seismic regulations.

Materials and Methods

Brief introduction into the Algerian seismic regulations

Algerian seismic regulations [32] have evolved through the years, the actual seismic regulations: RPA 99 V2003 is considered the fifth regulation after RPA 81, RPA81 V1983, RPA 88, and RPA 99. The development of the Algerian seismic regulations took into account the progress in the research field, and the lessons learned from earthquakes in Algeria, such as those of Oued Djer (October 1988), Tipaza (October 1989), Mascara (August 1994), and abroad, such as Spitak / Armenia (1988), Sanjan / Iran (1990), Loma Priéta / California (1989), Northridge/California (1994), Kobe/Japan (1995), and Izmit/Turkey (1999). According to [32], the Algerian territory is divided into five (05) zones of increasing seismicity (Fig.1).

Zone O: negligible seismicity.

Zone I: low seismicity.

Zone IIa and IIb: average seismicity.

Zone III: high seismicity.

The Algerian seismic regulations [32] classify buildings according to their importance into four (04) groups, The minimum level of seismic protection granted to a structure depends on its destination and its importance with regard to the protection objectives. The classification aims to protect people, then economic goods and cultural aspects of the community.

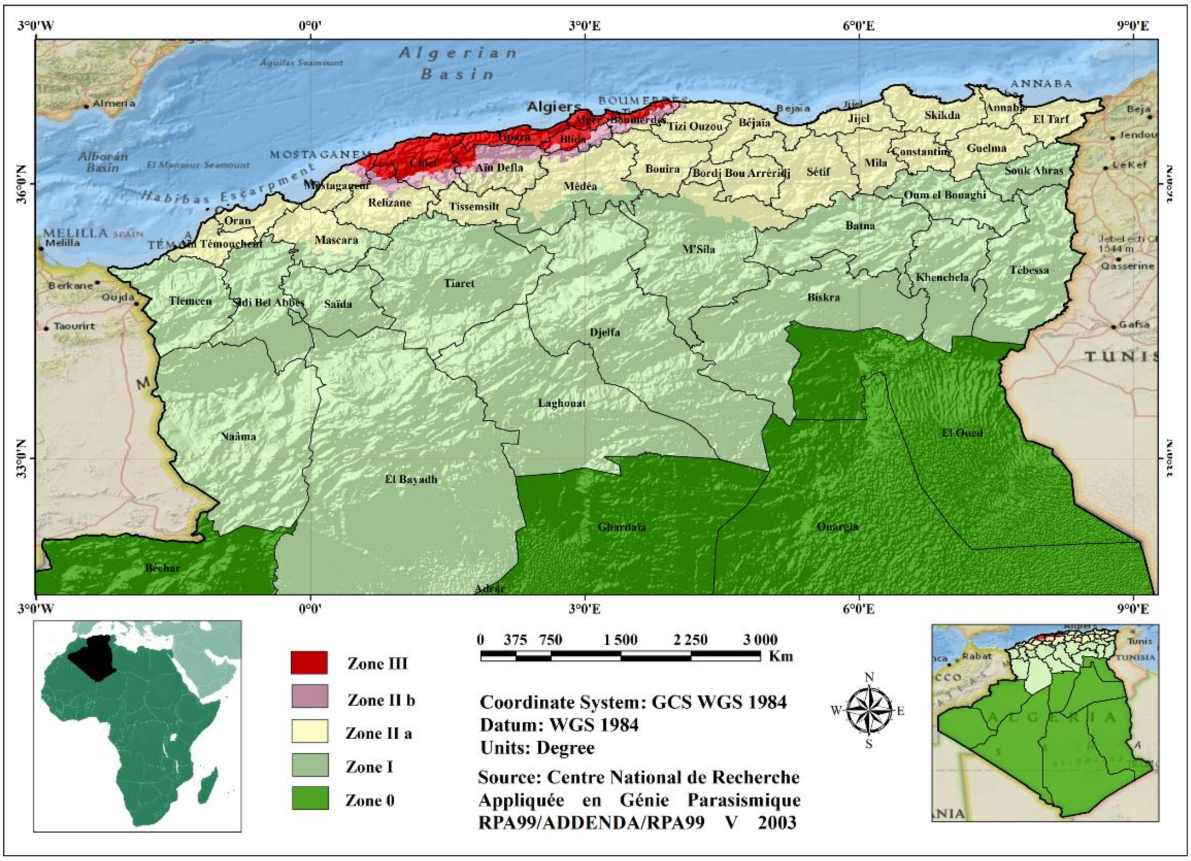

Fig. 1. *Seismic zones in Algeria [32]*

Group 1A: Buildings of vital importance.

Group 1B: Buildings of major importance.

Group 2: Common buildings or of a medium importance.

Group 3: Buildings of minor importance.

Accordingly, the Algerian seismic regulations give the following zone acceleration coefficients (Table 1).

Table 1. Zone acceleration coefficient [32]

	Zone			
Importance	I	IIa	IIb	III
1A	0.15	0.25	0.30	0.40
1B	0.12	0.20	0.25	0.30
2	0.10	0.15	0.20	0.25
3	0.07	0.10	0.14	0.18

As for the construction sites, the Algerian seismic regulations [32] classify them into four (04) categories based on the mechanical properties of the soil which constitute them.

Category S1 (rocky site): rock or other geological formation characterized by an average shear wave speed (VS) ≥ 800 m/s.

Category S2 (firm site): deposits of very dense sand and gravel and/or overconsolidated clay 10 to 20m thick with VS ≥ 400 m/s below 10m depth.

Category S3 (loose site): thick deposits of moderately dense sand and gravel or moderately stiff clay with VS ≥ 200 m/s below 10m depth.

Category S4 (very loose site):

- deposits of loose sand with or without the presence of layers of soft clay with VS < 200 m/s in the first 20 meters.

- soft to moderately stiff clay deposits with VS < 200 m/s in the first 20 meters.

The analyzed model

In order to assess the impact of green roofs on the seismic performance of collective housing in Algeria, a typical building is chosen as shown in Figure 2. This building is located in the district of Constantine (northern east of Algeria), which falls under the IIa seismic zone. The IIa zone was chosen because it covers a large zone in the northern part of Algeria extended from the east to the west, and known for its important population density. The building importance is classified according to the Algerian seismic regulations in group 2 (common buildings or of medium importance); this category contains buildings for collective housing or office use in which the height does not exceed 48m, other buildings that can accommodate a maximum of 300 people simultaneously, such as office buildings, industrial buildings …etc., and public parking lots. The chosen collective housing is built on a loose site (site of category S3 [32]).

The analyzed building is composed of six floors, each floor is composed of 4 apartments that share one staircase. The overall area of each floor is about 356m^2. The height of each floor is 3.06m, thus, the total height of the building is 18.36m. The cross section of columns varies between 1600 and 1800cm^2. As for the roof, it is inaccessible with a waterproof isolation covered by river gravel.

Fig. 2. *Picture of the analyzed collective housings*

The structural system consists of concrete load-bearing walls (15cm thick) and reinforced concrete (RC) frames. According to the Algerian seismic regulations [32], RC framed buildings with rigid masonry walls (rigid masonry walls are the common separation walls in Algerian buildings) must not exceed five (05) levels or seventeen (17) meters in seismic zone I, four (04) levels or fourteen (14) meters in zone IIa, three (03) levels or eleven (11) meters in zone IIb and two (02) levels or eight (08) meters in zone III. If the aforementioned heights are exceeded, buildings must include concrete load-bearing walls.

The bracing system consists only of concrete load-bearing walls, since in the studied model, the concrete load-bearing walls absorb more than 20% of the forces due to vertical loads [32]. As for the floor, it is made of a hollow block slab that transfers the vertical loads in the X direction. This later is assumed to be fully rigid, i.e., it transfers all the lateral loads to the bearing walls. Regarding the weight of the floors, it was calculated accounting for the hollow block slab and the materials used in floor covering, a value of 5.25 KN/m^2 is adopted for the studied case. In the present study, the compressive strength of the concrete is 25 MPa.

Since the building's roof is already equipped with water-proof isolation covered by river gravel, and the drainage system is already in place, the green roof is considered to be installed directly on the building, as demonstrated in Figure 3. The soil depth varied between 10cm (shallow green roof) and 50cm (deep green roof). The weight of the green roof is calculated using the saturated soil density (19 KN/m^3) and accounting for the weight of the plants as (0.45 KN/m^2). As for the live load, it is considered as maintenance load of 1 KN/m^2.

The building was modeled using the finite element code Robot structural analysis (Fig.4). A modal analysis was performed first, followed by a seismic analysis according to the Algerian seismic regulations. For the

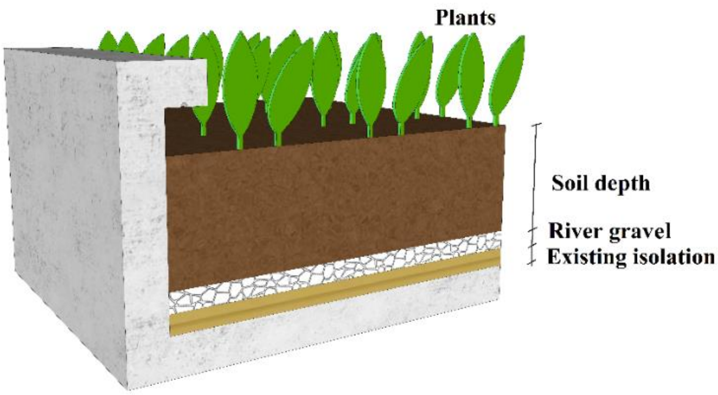

Fig. 3. *Schematic illustration of the green roof*

generation of finite elements, the nodes are generated at the intersection of vertical/horizontal bars. The tolerance of structure model generation for the analyzed model is 0.1mm. Regarding load-bearing walls, for the mesh generation, an element size of 0.5m was adopted. In this study, only the seismic performance-related parameters were analyzed.

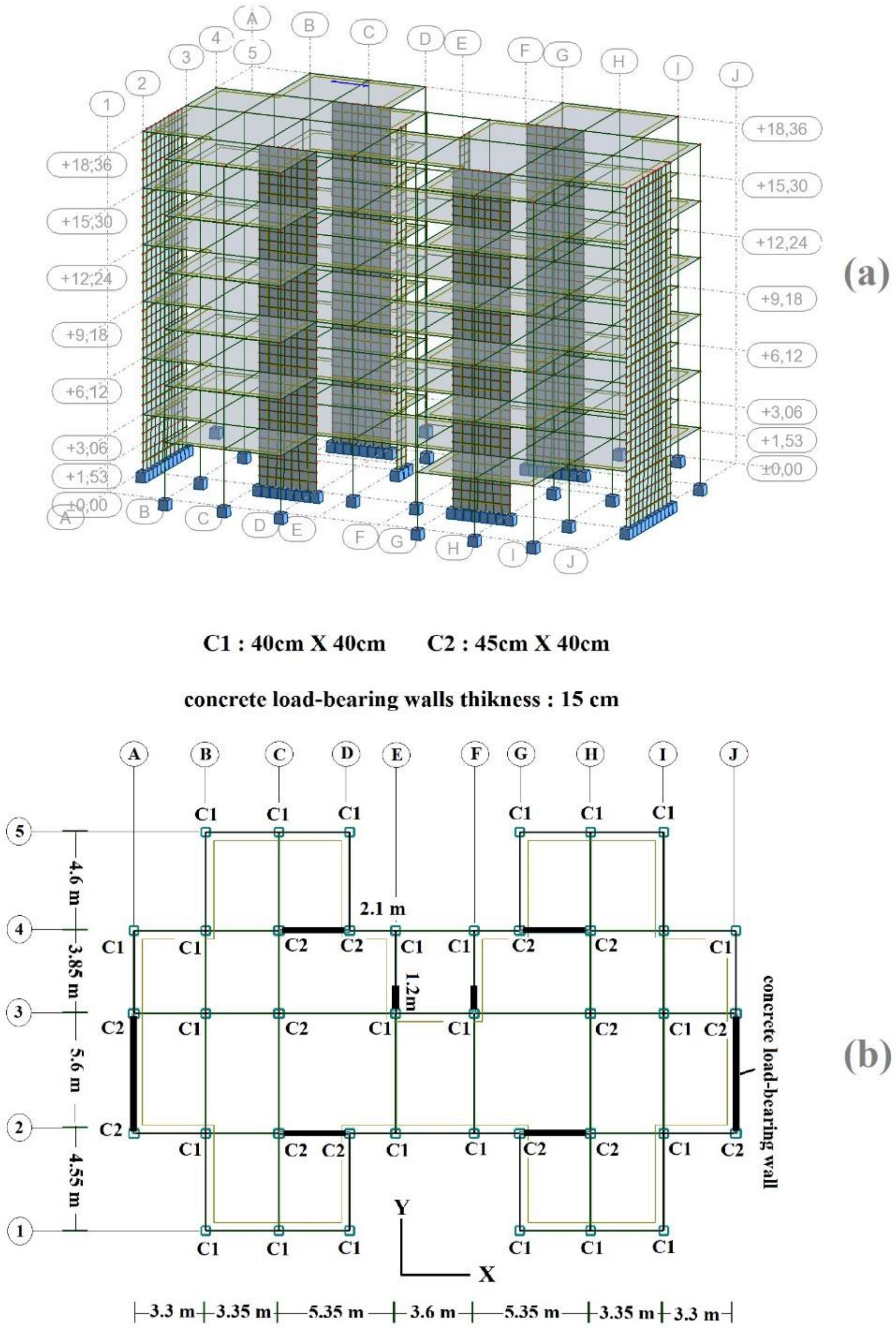

Fig. 4. *The 3D (a) and the building plan (b) of the analyzed numerical model*

Results and Discussion

In the present paper, the seismic performance of a collective housing with green roof retrofitting in Algeria is investigated according to the Algerian seismic regulations [32]. In order to assess the impact of green roofs on the seismic performance of this building, the natural period of the building, reduced normal forces in columns, peak storey drift, relative displacement, shear forces at the base, and overturning moment are investigated.

Effect of the green roof on the natural period of the building

It is meant by the natural period of a building, the time taken by it to undergo one complete cycle of oscillation. The value of the fundamental period (T) of the structure can be estimated from empirical formulas or calculated by analytical or numerical methods. The empirical formulas to use are as follows [32]:

$$T = Ct.hn^{3/4}\ , \qquad (1)$$

h_n : height measured in meters from the base of the structure to the last level (n).
C_t : coefficient, function of the bracing system, type of separation walls. In this case study: "Bracing provided partially or totally by concrete load bearing walls, triangulated blocks and masonry walls" Ct = 0.05.
And:

$$T = \frac{0.09\ hn}{\sqrt{L}}\ , \qquad (2)$$

where L is the dimension of the building measured at its base following the considered calculation direction. In this case, it is appropriate to retain, in each direction considered, the smaller of the two values given, respectively, by formulas (1) and (2).

In the present study, the soil depth of the green roof is varied from zero (building without green roof) to fifty centimeters (building with deep green roof), the period of building varies as plotted in Figure 5.

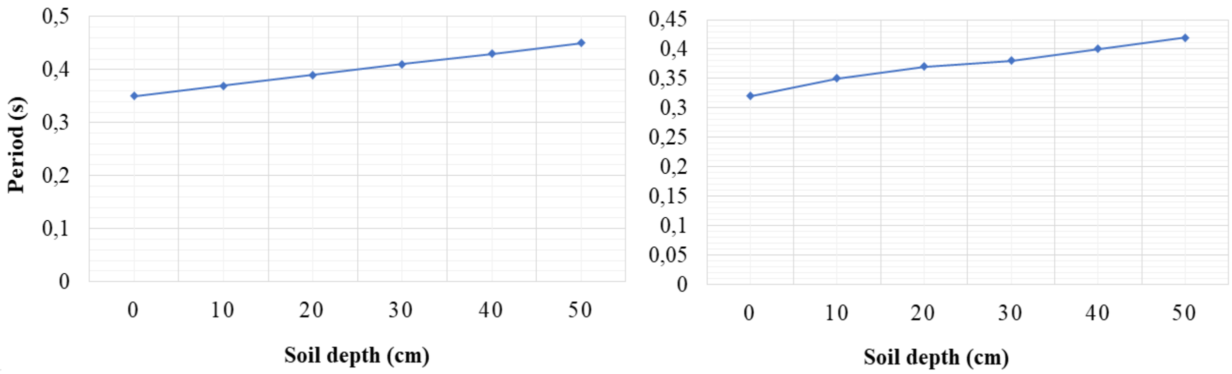

Fig. 5. *Analytical period of the structure in X direction (left side), and Y direction (right side)*

As plotted in Figure 5, the analytical period increases with the increase of the depth of the green roof in both X and Y directions (see Figure 4 for X and Y axes). As for the fundamental period calculated using formulas (1) and (2), they are 0.31s in the X direction and 0.38s in the Y direction.

For the X direction, the analytical period is greater than the fundamental one (0.31s) for all green roof depths, however, in the Y direction, the analytical period is less than the fundamental one (0.38s) for green roof depth less than 30cm and greater for green roof depths 40 and 50cm.

The tolerated analytical period should be less than 1.3 times the fundamental one [32]. In this case, less than 0.40s in the X direction, and 0.49s in the Y direction. For the present study, the periods in the building with 30, 40, and 50cm green roof depth in the X direction offered a greater period than that tolerated by the Algerian seismic regulations. Thus, for all the other configurations, the building periods obey the Algerian seismic regulations. This can be explained by the fact that the presence of load-bearing walls in the building contributes to a more rigid behavior of this later.

Effect of the green roof on peak storey drift

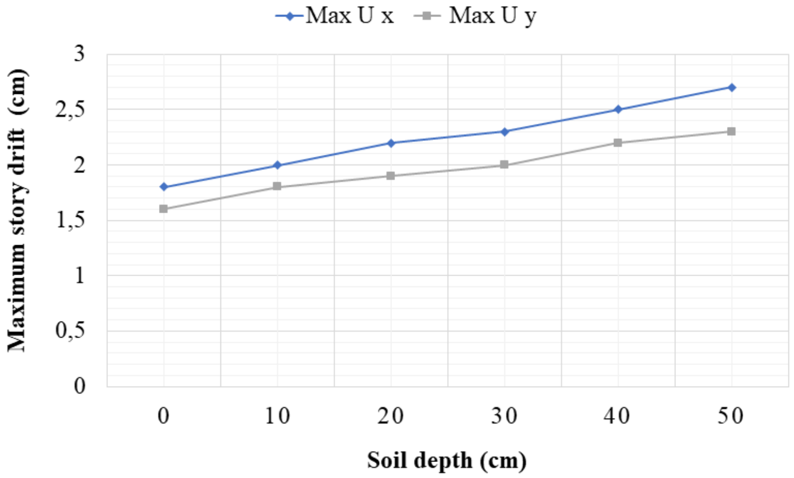

Fig. 6. *Variation of the maximum top storey drift with respect to the green roof soil depth in X and Y directions*

Adding more weight on the top of an existing building will logically cause the maximum storey drift to increase during an earthquake event. Thus, when adding a green roof to an existing building, it is important to make sure that the maximum storey drift at the top is not high enough to collide with the adjacent building.

In the present study, the maximum storey drift with respect to the green roof soil depth is analyzed as shown in Figure 6.

It is noticeable for both directions that the peak storey displacement increases with the increase of soil depth. In the X direction, the increase of top storey maximum displacement (Max Ux) between the building without green roof and the one with 50cm green roof is 0.9cm, and for the Y direction (Max Uy) it is 0.7cm. This increase is not very substantial due the presence of load-bearing walls.

Effect of the green roof on relative storey displacement

By definition, the relative displacement at level "k" with respect to level "k-1" is equal to:

$$\Delta_k = \delta_k - \delta_{k-1} \quad . \tag{3}$$

The lateral relative displacements of a storey relative to the storey adjacent to it, must not exceed 1.0% of the height of the storey unless it can be proven that a larger relative displacement can be tolerated [32].

In the present study, the relative displacement for each storey increases with the increase of the green roof's soil depth. The tolerated relative displacement should be less than 1% of storey height, thus less than 3.06cm, which is the case for all green roof soil depths (Fig.7).

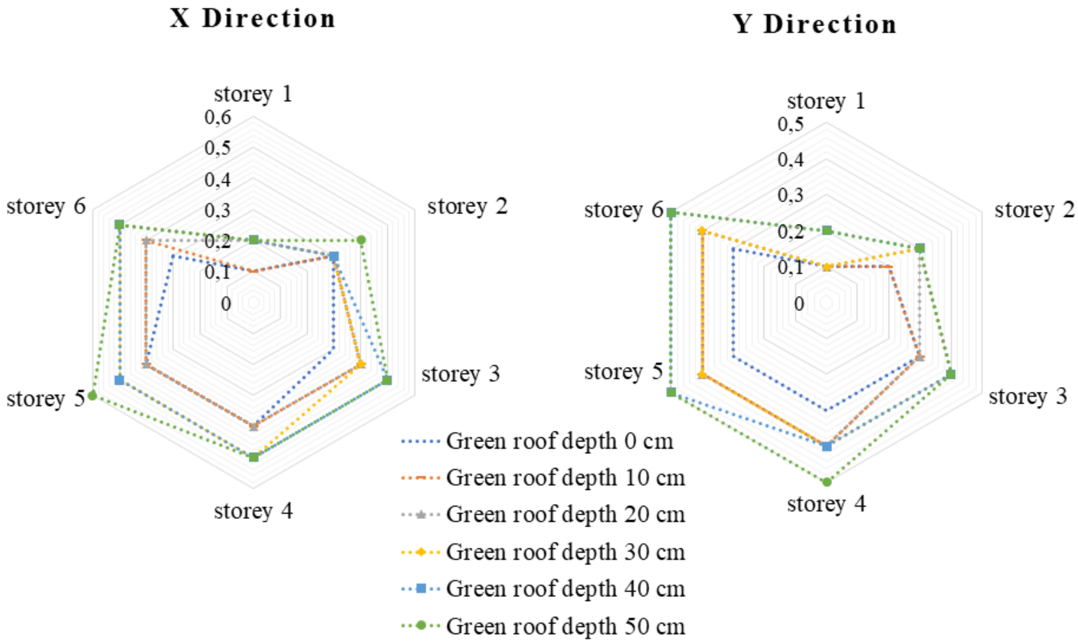

Fig. 7. *Variation of relative storey displacement (cm) with respect to the green roof soil depth in X and Y directions*

Effect of the green roof on reduced normal force

The reduced normal force is restricted in order to avoid or limit the risk of brittle failure under overall stresses due to the earthquake. The threshold for the reduced normal force in columns is 0.3. This later is calculated using the formula [32]:

$$\nu = \frac{Nd}{Bc.fcj}\ , \tag{4}$$

where Nd indicates the normal force applied on a column section of concrete during the event of an earthquake; Bc is the area of the column; fcj is the compression strength of the concrete (25 MPa).

As plotted in Figure 8, it is clear that the reduced normal force increases with the increase of green roof depth, however, for all soil depths, the reduced normal force is less than the threshold recommended by the Algerian seismic regulations.

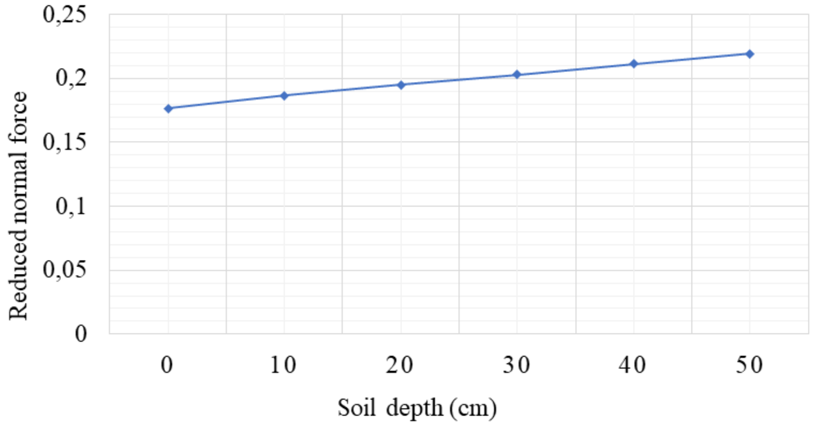

Fig. 8. *Variation of reduced normal force with respect to green roof soil depth*

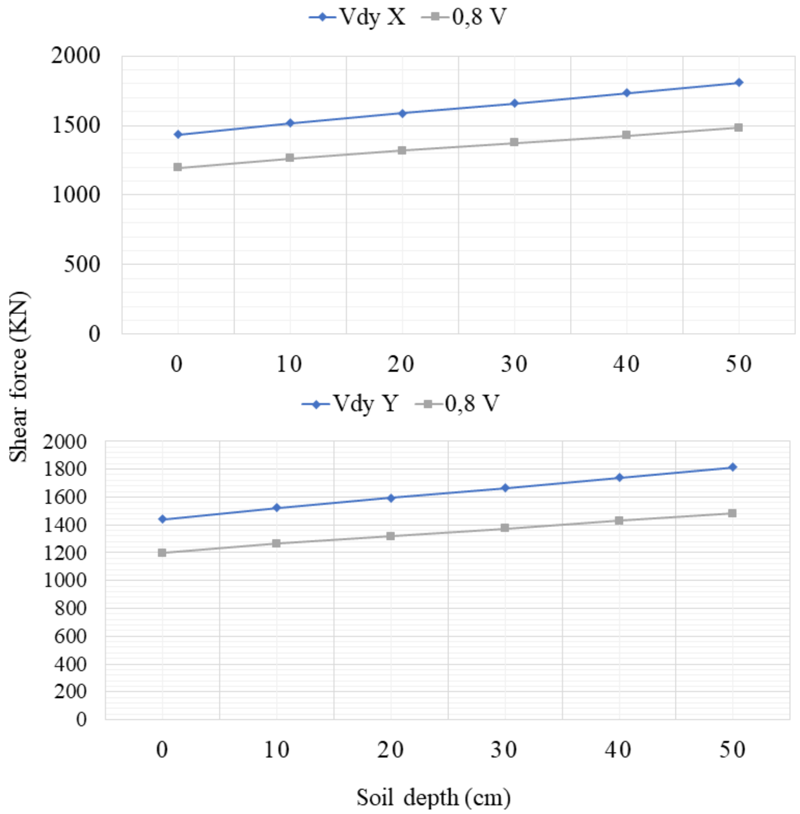

Fig. 9. *Variation of shear forces at the base with respect to green roof soil depth in X direction, and Y direction compared to 0.8 V*

Effect of the green roof on shear forces at the base

At the base of the structure, the resultant of the seismic forces (Vt) calculated by combining the model values must not be less than 80% of the resultant of the seismic forces given by the equivalent static method (V), for a value of the fundamental period specified by the appropriate empirical formula [32].

If Vt < 0.80 V, it will be necessary to increase all the parameters of the response (forces, displacements, moments...etc.) in the ratio 0.8 (V/Vt) [32]. Figure 9 shows the variation of shear forces at the base with respect to green roof soil depth in X and Y directions.

The total seismic force V, applied to the base of the structure, must be calculated successively in two orthogonal horizontal directions according to the formula [32]:

$$V = \frac{A.D.Q.W}{R}\ , \tag{5}$$

A: zone acceleration coefficient,
D: average dynamic amplification factor,
Q: quality factor,
W: total weight of the structure,
R: coefficient of the global behavior of the structure.

As shown in Figure 9, the shear forces at the base increase with the increase of soil depth. In both X, and Y directions, the shear forces for a building with the deepest green roof (50cm) are around 125% of that without a green roof, which represents a significant increase in the shear forces due to green roof implementation.

Effect of the green roof on overturning moment

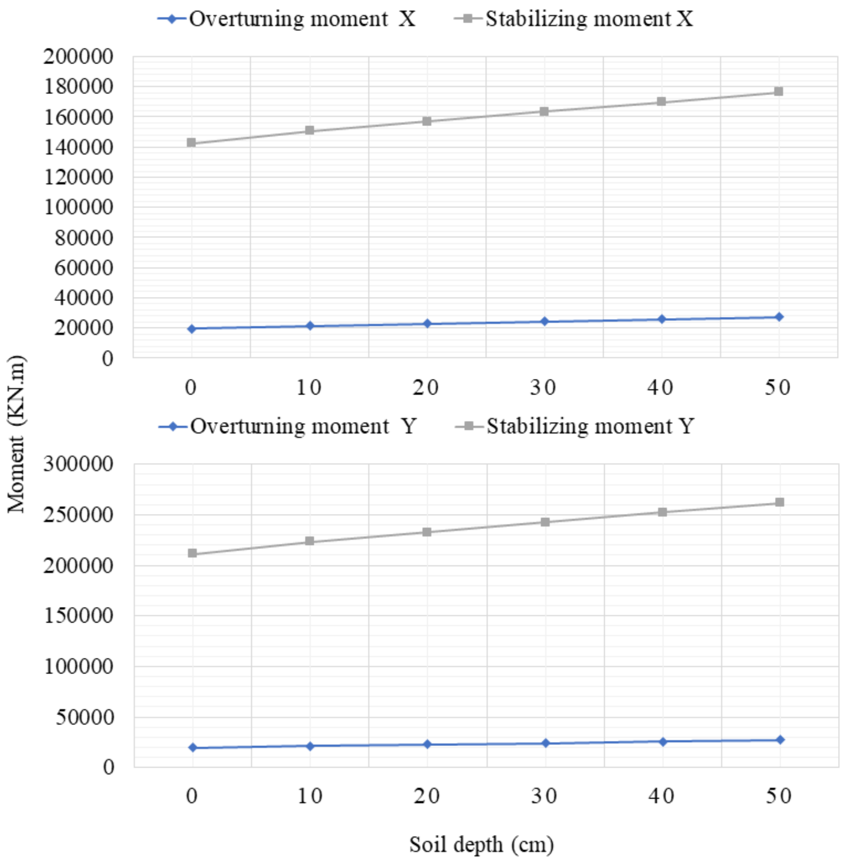

Fig. 10. *Variation of overturning and stabilizing moment in X and Y directions*

The overturning moment caused by an earthquake is an important parameter that must be included in seismic performance analysis. When it comes to green roofs, the weight of this later participates in both overturning moment and stabilizing moment. As shown in Figure 10, the stabilizing moment is much greater than the overturning one. Also, both overturning and stabilizing moments increase with the increase of green roof soil depth, however, the increase in the stabilizing moment is much significant, thus, adding a green roof contributes more to the stabilizing moment than to the overturning one.

Conclusion

Green roofs offer many advantages with regards to reducing energy consumption, mitigating the urban heat island effect, improving air pollution, managing runoff, increasing sound insulation, and preserving the ecological environment. All these qualities make green roofs a very sustainable technique for the ecological transition. However, in order to propagate this technique, green roofs have to be installed on the top of existing buildings, which can increase their vulnerability during seismic events. In this research, the seismic performance of collective housing with green roof retrofitting in Algeria is investigated according to the Algerian seismic regulations.

It was found that the presence of load-bearing concrete walls, recommended by the Algerian seismic regulations, has a certain positive effect on green roof installation with regard to the seismic performance. The presence of these walls increases the rigidity of the building which reflects positively on the building natural period and displacements, thus, even with the loads generated by the green roof installation, most of the displacement-related parameters remained obeyed to the Algerian seismic regulations.

As for the stress-related parameters, the reduced normal stress does not increase much, however, the shear forces at the base for the building with a deep green roof are around 125% of that without a green roof, which represents a significant increase in the shear forces due to green roof implementation.

Both overturning and stabilizing moments increase with the increase of green roof soil depth, however, the increase in the stabilizing moment is much significant, thus, adding a green roof contributes more to the resisting moment than to the overturning one.

In the studied context, the presence of load-bearing concrete walls offers certain positive effects on green roof installation with regard to seismic performance. Nevertheless, a thorough seismic investigation should be performed before installing green roofs on the top of existing collective housing in Algeria.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

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TRANSFORMATIVE EFFECTS OF SALINITY ON SEBKHA SOIL PROPERTIES: UNVEILING STRENGTH, STRUCTURE, AND STABILITY THROUGH ADVANCED REMEDIATION STRATEGIES

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Abstract: *This study investigates the effects of varying salinity levels on sebkha soils, focusing on their physical, mechanical, and chemical properties. Soil samples were collected from Tin silt sebkha in Ain M'lila across three different seasons, resulting in high salinity soil (HSS), medium salinity soil (MSS), and low salinity soil (LSS). The grain size distribution curves reveal that 70% of grains in both HSS and LSS have diameters less than 60 µm, with LSS containing 19% more particles smaller than 20 µm compared to HSS. Unconfined compressive strength (UCS) measurements show a significant decrease from 1100 kPa in LSS to 200 kPa in HSS, with corresponding peak strains increasing from 2.3% to 4.7%. Chemical analysis indicates that pH decreases from 8.17 in LSS to 6.79 in HSS, reflecting increased soil acidity with higher salinity. SEM images demonstrate that higher salinity results in a denser soil structure due to salt cementation, whereas lower salinity soils exhibit more micropores. The study highlights the need for comprehensive models integrating these properties to enhance predictive capabilities and inform effective soil management. Future research should explore remediation strategies using additives to improve soil strength and stability, addressing the challenges posed by salt dissolution and soil degradation.*

Keywords: *salinity, sebkha soil, grain size distribution, unconfined compressive strength, soil pH, SEM analysis, soil remediation, predictive modeling.*

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Received: 08.09.2024
Revised: 01.10.2024
Accepted: 12.10.2024

Introduction

Problematic soils are globally prevalent and pose considerable challenges to civil engineering infrastructures, often leading to costly damage and structural failures [1, 2]. Among these, collapsible soils are particularly notorious due to their sudden loss of strength upon wetting. Houston et al. [3] identified collapsible soils as one of the most problematic geomaterials in the field of geotechnical engineering, and the study of their behavior is essential for designing foundations and other civil structures. Sabkha soils, a specific type of unsaturated collapsible soil, are particularly troublesome in arid and semi-arid regions [4-7]. Their high soluble salt content and low clay fraction promote the formation of a macroporous structure, where soil particles are loosely bonded [8]. Under dry conditions, the salt phases act as a cementing agent, stiffening the soil structure. However, exposure to water triggers the dissolution of these crystalline phases, destabilizing the bonds and drastically reducing the soil's strength, which can lead to catastrophic settlement or collapse [8].

In recent decades, researchers have increasingly focused on understanding the complex behavior of saline soils, given their widespread occurrence in coastal and desert regions. Ying et al. [9] observed that compaction properties remain relatively unaffected by varying salinities, primarily due to the low clay content, which limits the influence of salinity on the diffuse double layer. However, Li et al. [10] demonstrated that the higher the chloride content is, the more likely the agglomerates are to appear in the soil, altering its microstructure. Hafhouf et al. [11] further highlighted the vulnerability of sabkha soils to drying-wetting cycles, showing that prolonged leaching significantly reduces soil salinity from 16.3 dS.m-1 to 3.8 dS.m-1, with the corresponding soil strength decreasing by almost 50%, from 325 kPa to 175 kPa. Similarly, Modmoltin et al. [12] found that soil salts could mitigate some of the negative effects of organic matter on treated soils, while Li et al. [13] demonstrated that chloride salts weaken the mechanical properties, such as unconfined compressive strength, even if compaction remains largely unaffected. Moreover, Xing et al. [14] identified that chloride ions (Cl-) have the most detrimental impact on the strength properties of saline soils, followed by magnesium (Mg2+) and sulfate (SO42-), indicating that the chemical composition of salinity plays a pivotal role in determining soil behavior.

Despite these efforts, there remains a notable divergence of opinions in the scientific community regarding the effects of salinity, especially in relation to soil strength. Some studies report a stabilizing effect of certain salts, while others emphasize their destructive impact on soil cohesion and mechanical integrity [15-17]. These discrepancies are largely attributed to the complex interplay between different types of salts, which is often not fully accounted for in studies focusing on a single ion [18]. Furthermore, the role of microstructure is increasingly recognized as a critical determinant of macroscopic behavior. Foncea et al. [19] emphasized the influence of natural soil structure, classifying soils into macroporous and microporous categories, each with distinct permeability and strength characteristics. This highlights the need for a more integrated approach, combining both chemical and structural analyses, to fully capture the effects of salinity on soil performance [20].

The primary objective of this study is to address these gaps by investigating the combined effect of chloride and sulfate salts on the physical, chemical, and mechanical properties of saline soils. The research aims to provide a more comprehensive understanding of how varying salt concentrations affect soil behavior under different environmental conditions, particularly in relation to its strength, compaction, and permeability. Furthermore, advanced microstructural analysis using Scanning Electron Microscopy (SEM) will be employed to elucidate the interaction between salt phases and soil particles, linking microscopic changes to macroscopic behavior. By bridging the gap between microstructural and macrostructural analyses, this study seeks to offer new insights into the mechanisms governing the behavior of saline soils, particularly in complex environments where multiple salts interact. These findings will have practical implications for geotechnical design, offering strategies for mitigating the risks associated with saline and collapsible soils in infrastructure projects.

Materials and Methods

Soil samples were collected from the Tin silt sebkha in Ain M'lila using a hydraulic excavator, at a depth of 1 to 2 meters below the surface. This sampling was conducted during three distinct seasons: summer, spring, and winter, resulting in three different salinity levels: highly saline soil (HSS), moderately saline soil (MSS), and slightly saline soil (LSS). The classification of these salt-affected soils follows the guidelines established by the US Salinity Laboratory Staff [21]. After collection, the samples were air-dried, gently crushed using a plastic hammer to avoid contamination, and then sieved through a 2 mm mesh to remove larger particles.

Ying et al. [9] demonstrated that the salinity levels have an insignificant effect on the Atterberg limits of soils with low clay content. As a result, only the geotechnical characteristics of HSS are presented in Table 1, since variations in salinity did not significantly alter these properties for the other samples. The highly saline soil (HSS) was classified as Lean Clay (CL) according to the Unified Soil Classification System (USCS). The chemical composition of HSS, shown in Table 2, reveals the dominance of chloride (Cl-) and sulfate (SO4^2-) ions, with concentrations of 3585 mg/l and 4704 mg/l respectively, indicating the presence of halite and gypsum phases. According to Loyer (1991), the soil's pH of 6.79 classifies it as a neutral chloride-sulfate soil.

Table 1. The geotechnical characteristics of HSS

Soil parameters	Methods	Values
Liquid limit LL		34.00
Plastic limit PL	(ASTM D4318-00, 2000	17.300
Plasticity index PI		16.70
≤ 2 mm fraction (%)	(NF P94-056, 1996)	98
≤ 80 µm fraction (%)		68
≤ 2 µm fraction (%)	(NF P94-057, 1992)	3
USCS	(ASTM D2487-00, 2000)	CL

Regarding soil compaction characteristics, such as optimal dry density (δdopt) and optimal water content (wopt), it was observed that the salinity levels had a negligible impact, a finding consistent with that of Ying et al. [9]. Therefore, all three soil types—HSS, MSS, and LSS—were compacted at their respective optimum water contents, which remained constant across varying salinity levels. This consistency suggests that, despite significant chemical differences, the mechanical response of the soil to compaction is not strongly influenced by salinity within the studied range.

Table 2. The chemical composition of the soluble salt content of HSS

ECe ($dS.m^{-1}$)	Salinity ($g.l^{-1}$)	pH	Soluble salt content ($mg.\ l^{-1}$)						
23.2	14.84	6.79	Na^{2+}	K^{2+}	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
			2323	50	391.2	156.5	10	3585	4704

Results and Discussion

Granulometry

Figure 1 demonstrates the grain size distribution curves (GSDC) of sebkha soil across varying salinity levels, revealing the significant influence of salinity on particle size distribution, particularly within the silt grain range. The non-convergent trend between slightly saline soil (LSS) and highly saline soil (HSS) underscores the complex interplay between soil salinity and granulometry. For both LSS and HSS, approximately 70% of the particles exhibit diameters smaller than 60 µm, yet when examining finer fractions, the divergence becomes more apparent. For LSS, 57% of the grains fall below 20 µm in diameter, whereas for HSS, only 38% do, representing a 19% increase in fine particles for LSS compared to HSS.

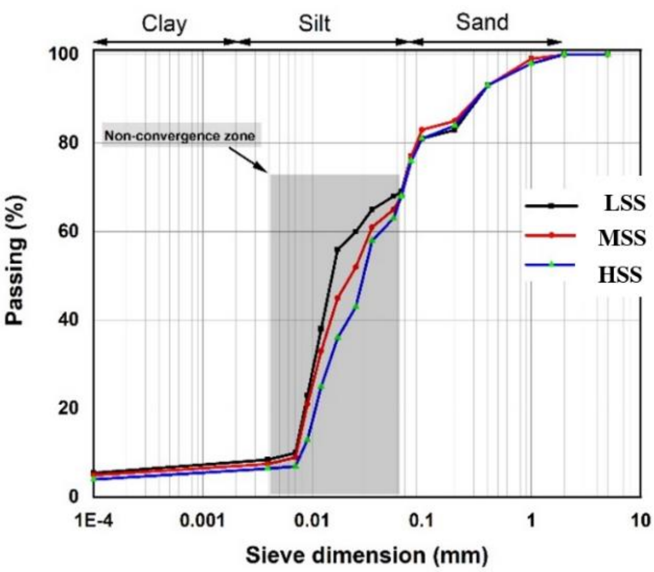


Fig. 1. *The grain size distribution curves of the three sabkha soils*

This variation can be explained by the presence of soluble salts such as halite (NaCl) and gypsum ($CaSO_4 \cdot 2H_2O$) in HSS [22]. These salts act as cementing agents between soil particles, especially within the silt fraction, due to the larger specific surface area of silt particles relative to sand grains [23]. The specific surface area is a critical factor in geotechnical engineering, as it dictates the degree of interaction between particles and binding agents. In dry conditions, halite and gypsum form strong crystalline bonds that stabilize larger aggregates, effectively reducing the proportion of fine particles. However, upon exposure to moisture, the dissolution of these salts weakens the interparticle bonds, leading to the disintegration of aggregates and an increase in the proportion of finer particles [24].

The impact of salinity on particle size distribution is closely linked to the microstructural properties of the soil. Silt particles, with their higher specific surface area, are more susceptible to salt cementation compared to coarser sand grains. This interaction leads to the formation of larger aggregates in saline environments, but when subjected to wetting-drying cycles, the breakdown of these aggregates results in a shift towards finer particle fractions. Such behavior is consistent with findings by Li et al. [13], who observed that increased chloride salt concentrations induce crystallization and flocculation, thereby increasing the proportion of particles greater than 2 µm. This suggests that chloride salts play a fundamental role in modifying soil structure through the crystallization of salt phases, leading to temporary stabilization that is disrupted during dissolution processes.

Furthermore, the differential behavior between HSS and LSS can be attributed to the chemical composition of the soils. HSS contains a higher concentration of soluble salts, which enhances the cementing effect between soil particles. These salts form a rigid matrix that holds the particles together, leading to larger aggregates and a reduced proportion of fine particles in dry conditions. Conversely, LSS, with a lower concentration of salts, exhibits less aggregation, resulting in a higher proportion of fine particles. The dissolution of salts in HSS causes the breakdown of these aggregates, thereby increasing the fraction of fine particles under moist conditions. This process is particularly relevant in sebkha soils, which experience fluctuating moisture levels due to environmental conditions, leading to cycles of salt precipitation and dissolution that significantly alter soil structure.

The presence of gypsum and halite in sebkha soils, especially in the silt fraction, is further supported by their high solubility in water, making them highly susceptible to dissolution. When exposed to moisture, these salts dissolve, weakening the soil's structural integrity and leading to a loss of cohesion between particles. This results in an increase in the proportion of finer particles, as previously cemented aggregates disintegrate. This behavior is critical for understanding the geotechnical performance of saline soils, particularly in regions where seasonal variations in moisture can lead to dramatic changes in soil stability.

Additionally, the limited clay content in the tested sebkha soil explains why the effect of salinity on the clay fraction is minimal. Clay particles, known for their plasticity and water retention capabilities, typically respond to salinity through changes in the diffuse double layer and interparticle forces. However, due to the low clay fraction, these effects are negligible in the current study, and the influence of salinity is predominantly observed in the silt fraction. Ying et al. [9] also noted that for soils with a low clay fraction, salinity has little to no effect on the Atterberg limits, further supporting the hypothesis that the observed behavior is primarily driven by interactions between soluble salts and silt particles.

In conclusion, the grain size distribution of sebkha soils is strongly influenced by salinity levels, with significant differences observed between LSS and HSS [25]. The cementing effect of soluble salts such as halite and gypsum plays a crucial role in stabilizing soil aggregates, particularly in the silt fraction, while the dissolution of these salts during wetting cycles leads to the disintegration of aggregates and an increase in fine particles [26].

Stress-strain curves of unconfined strength tests

The stress-strain curves presented in Figure 2 illustrate the results of unconfined compressive strength (UCS) tests for sebkha soils with varying salinity levels. The stress-strain behavior of these soils is influenced significantly by salinity, with a marked decrease in peak strength prior to failure across all samples. A key observation is that soils with higher salinity exhibit a more pronounced ductile behavior, meaning that peak strength is attained at larger axial strains as salinity increases. This relationship is crucial in understanding the mechanical performance of saline soils in geotechnical applications.

In saline soils with higher salt content, such as halite (NaCl) and gypsum ($CaSO_4 \cdot 2H_2O$), the solid salt phases within the soil skeleton begin to dissolve under certain moisture conditions. Halite, being highly soluble, dissolves rapidly upon contact with water, transforming solid particles into fluid phases [27]. This dissolution leads to a loss of cohesion between soil particles, thereby disrupting the soil structure and resulting in a softer, more ductile response under loading. The mechanical disturbance caused by the dissolution of these salt phases explains the reduction in strength and the shift toward greater ductility, as the soil becomes less capable of resisting deformation [4].

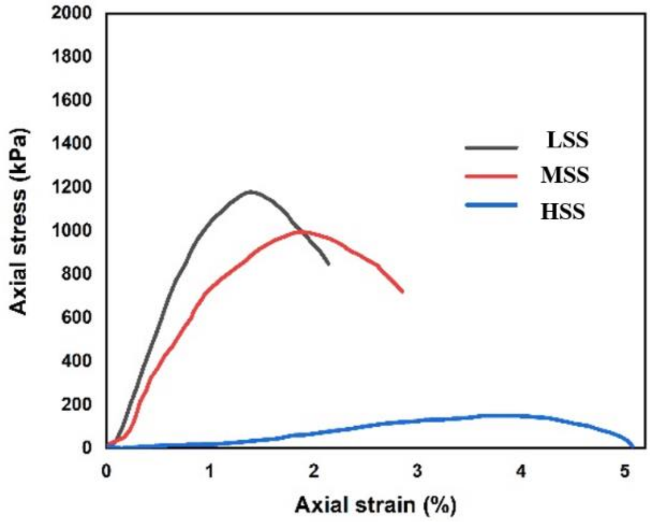


Fig. 2. *The stress-strain curves of compacted three sabkha soils*

In contrast, gypsum is less soluble compared to halite, which slows its dissolution process. However, even partial dissolution of gypsum can still contribute to the weakening of the soil matrix. The combined presence of these salts leads to a progressive softening of the soil, with increasing salinity exacerbating the degradation of the soil's structural integrity. As a result, the soil's capacity to bear loads decreases, which is evident from the stress-strain curves.

For the slightly saline soil (LSS), the dissolution phases are almost negligible due to the lower salt content. The low solubility of salts in LSS ensures that the soil structure remains largely intact, leading to a stiffer response during loading. This is reflected in the stress-strain curve, where the LSS displays a prominent peak at failure, indicating that the soil retains much of its original strength until a distinct failure point is reached. The pronounced peak in the blue plot (Fig. 2) represents this stiff behavior, as LSS maintains its cohesion and strength over a broader range of axial strain before failing suddenly, which is characteristic of more brittle materials.

The transition from stiff, brittle behavior in low-salinity soils to soft, ductile behavior in high-salinity soils can be attributed to the complex interplay between the dissolution of soluble salts and the resulting changes in the soil microstructure. As the salinity increases, the soil undergoes a shift in mechanical behavior from brittle failure, where the soil fractures and fails abruptly, to ductile deformation, where the soil continues to deform beyond the peak load without sudden failure. This behavior is indicative of the weakening bonds between particles, caused by the dissolution of salts [4].

The progressive ductile response with increasing salinity highlights the need for careful consideration of salinity in geotechnical design, particularly in regions with saline soils like sebkha environments. The softening of the soil structure due to salt dissolution can lead to significant settlement and deformation in engineering structures, particularly when subjected to loading over time. Therefore, understanding the stress-strain behavior of saline soils is essential for predicting their performance under real-world conditions, especially in areas where moisture fluctuations can exacerbate the dissolution of salts.

Unconfined compressive strength

Figure 3 illustrates the relationship between peak strength, axial strain, and salinity levels for sebkha soil samples subjected to unconfined compressive strength (UCS) testing. The peak strength (UCS) represents the maximum stress the soil can withstand before failure, while the slope of the stress-strain curve before failure indicates soil stiffness. Both the UCS and stiffness exhibit a decreasing trend with increasing salinity levels, highlighting the detrimental effect of salt content on the mechanical properties of sebkha soils.

For example, the UCS is only 200 kPa for highly saline soil (HSS), while it increases to 580 kPa for moderately saline soil (MSS) and reaches 1100 kPa for low salinity soil (LSS). These results suggest that salinity significantly weakens the soil structure, particularly in soils with high soluble salt content, such as halite and gypsum. The dissolution of these salts under certain moisture conditions compromises the integrity of the soil matrix, leading to a notable reduction in strength.

In contrast, the axial strain at failure exhibits the opposite trend. The strain at failure (ε) is much larger for HSS (ε = 4.7%) and MSS (ε = 4.2%) compared to LSS (ε = 2.3%). This inverse relationship between salinity and strain indicates that higher salt concentrations result in more ductile behavior, where the soil deforms more before reaching its failure point. The high ductility of HSS and MSS can be attributed to the dissolution of halite and gypsum, which causes the soil structure to soften and undergo greater deformation before failure. In LSS, however, the lower salt content limits the dissolution processes, resulting in a stiffer and more brittle response under loading.

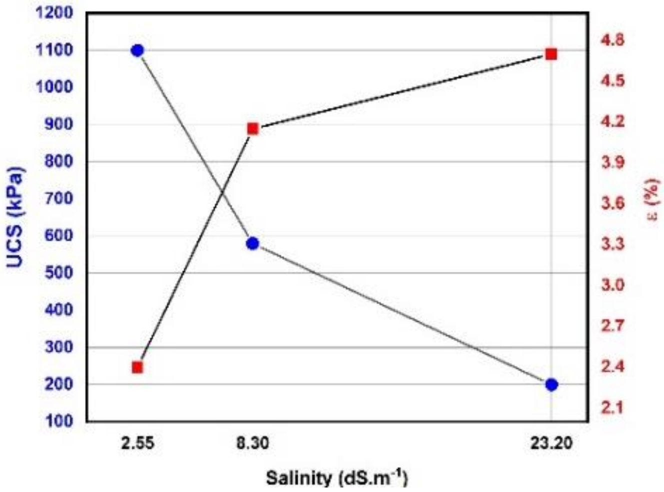


Fig. 3. *The peak strength and axial deformation of compacted three sabkha soils*

The variations in UCS and strain between MSS and LSS are more pronounced than those between HSS and MSS, indicating that the reduction in salinity from 8.30 dS.m-1 to 2.55 dS.m-1 has a more substantial effect on the soil's strength and stiffness compared to the reduction from 23.2 dS.m-1 to 8.30 dS.m-1. This finding can be explained by the relative solubility of the salts involved. In highly saline soils, halite is the dominant phase due to its high solubility, and it dissolves more readily when exposed to water. In contrast, in MSS, gypsum becomes the predominant phase, which is less soluble and has a more significant impact on the soil's mechanical properties.

The presence of gypsum in MSS plays a critical role in both strength and stiffness. While halite dissolves rapidly, leading to a softer soil structure, gypsum's slower dissolution process allows it to maintain some cohesion and strength within the soil matrix. However, when MSS is exposed to leaching, the gradual dissolution of gypsum can lead to a significant reduction in soil resistance. This makes MSS highly susceptible to strength loss during wetting-drying cycles, posing a potential risk for civil engineering works in saline environments. In this context, field conditions involving MSS warrant closer attention due to the greater risk of structural degradation over time.

In summary, the UCS and stiffness of sebkha soils increase as salinity decreases, with LSS demonstrating the highest strength and lowest strain at failure. Conversely, the ductility of the soil increases with salinity, as evidenced by the larger strains at failure for HSS and MSS. The sharp reduction in strength and stiffness between MSS and LSS highlights the critical role of gypsum in soil behavior, particularly in environments where salinity levels fluctuate. Given these findings, MSS soils in particular should be carefully monitored and managed in geotechnical applications to prevent excessive weakening under environmental stressors such as leaching.

Chemical Analysis

Seasonal climatic conditions play a critical role in influencing soil salinity through mechanisms such as capillary action and evaporation. The solubility of different salt phases in the soil is contingent on the salt type and its degree of crystallization, as well as the inherent structure of the soil (Foncea et al.[19]). In the case of the sebkha soil under study, chloride salts are predominant. Chlorides are highly soluble, which means they readily dissolve in moisture and migrate to the soil surface via capillary forces and evaporation. This process leads to a reduction in soil salinity as the chloride content diminishes over time.

In contrast, gypsum, which is also present in the soil, exhibits a lower solubility rate compared to chloride [28]. Gypsum's dissolution is less pronounced under the same conditions, leading to a slower decrease in soil salinity. This differential solubility influences the overall chemical composition and pH of the soil, as reflected in the chemical analysis results [29].

Table 3 provides an overview of pH variations across different salinity levels. It is observed that as soil salinity increases, there is a corresponding decrease in pH, indicating an increase in soil acidity. This trend is attributed to the high concentration of chloride ions in the soil, which contributes to a more acidic environment. Specifically, the soil at the highest salinity level (HSS, CE = 23.2 dS.m-1) shows a significant drop in pH, reflecting the strong acidic influence of chloride salts.

Table 3. The chemical analysis of compacted three sabkha soils

CE ($dS.m^{-1}$)	**pH**	**Salt content ($g.l^{-1}$)**
23.20 (HSS)	6.79	14.24
8.30 (MSS)	8.03	5.31
2.55 (LSS)	8.17	1.29

Conversely, when salinity decreases from 23.2 dS.m-1 to 2.55 dS.m-1, there is a notable increase in pH from 6.79 to 8.17, resulting in a more neutral environment. This shift is indicative of the reduced impact of acidic chloride salts and the relative dominance of less acidic phases, such as gypsum, which contributes to the neutralization of soil acidity. The variation in pH values underscores the dynamic interplay between different salt phases and their impact on soil chemistry.

The impact of salinity on pH is more pronounced when transitioning from high salinity levels (e.g., 23.2 dS.m-1) to lower levels (e.g., 8.30 dS.m-1), reflecting a more significant change in soil acidity. In contrast, the pH variations between lower salinity levels (e.g., 8.30 dS.m-1 to 2.55 dS.m-1) are less dramatic, suggesting that the soil's chemical environment stabilizes as salinity decreases.

This chemical behavior has practical implications for managing saline soils in agricultural and civil engineering contexts. High salinity levels can lead to increased soil acidity, which may adversely affect plant growth and soil stability. Conversely, lower salinity levels are associated with a more neutral pH, which can be more conducive to plant growth and soil health.

Microstructural Analysis (SEM)

Figure 4 provides insights into the microstructural characteristics of sebkha soil samples analyzed via Scanning Electron Microscopy (SEM). The observations reveal significant differences in the soil microstructure corresponding to various salinity levels.

High Salinity Soil (HSS)

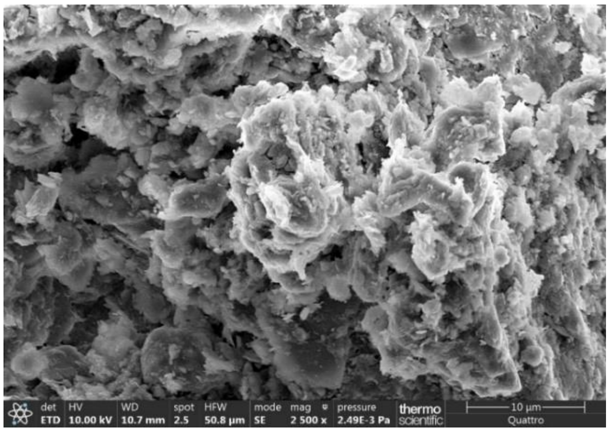
In Figure 4 (a), the SEM images of HSS illustrate the presence of well-defined crystalline salt phases. The soil's chemical composition, predominantly chlorine-sulfate, confirms that halite (NaCl) and gypsum ($CaSO_4 \cdot 2H_2O$) are the main compounds. Halite typically appears as white, platelet-like crystals, whereas gypsum exhibits a more random and varied morphology. These salt crystals contribute to a denser soil structure through their cementing action. The halite and gypsum crystals act as binding agents, creating a cohesive matrix of soil particles. The interlocking of these crystals with soil particles forms a robust network that enhances the soil's initial strength and stiffness. However, the stability of this structure is contingent upon the salt phases remaining intact.

Low Salinity Soil (LSS)

In contrast, the SEM images of LSS reveal a different microstructural arrangement. The lower salt content in LSS results in a less dense structure with more noticeable micropores between the soil aggregates. This porous texture is likely due to the reduced presence of soluble salts like halite and gypsum, leading to fewer cementing agents within the soil matrix. Additionally, the lower clay content in LSS may contribute to the more pronounced appearance of micropores, as the reduced clay fraction limits the overall cohesion and binding capacity of the soil [25].

The effect of salinity on soil microstructure is evident in the observed changes. Higher salt content results in a denser and more cohesive soil structure due to the cementing effect of halite and gypsum [25]. However, when the soil is exposed to water, the solubility of these salts comes into play. Halite, being highly soluble, dissolves readily upon moisture exposure, which disrupts the cementing bonds and weakens the soil structure. Gypsum, while less soluble, still contributes to structural changes over time. The leaching process, wherein salts are washed out from the soil surface, creates additional micropores and alters the particle arrangement, resulting in a more porous and less cohesive structure.

The dissolution of salts through leaching significantly impacts the soil's mechanical properties. As the cementing salts are removed, the previously bound soil particles are left with reduced cohesion, leading to a decrease in soil strength and stiffness. This shift in the microstructural arrangement highlights the importance of considering salinity and its impact on soil behavior in practical applications [30].



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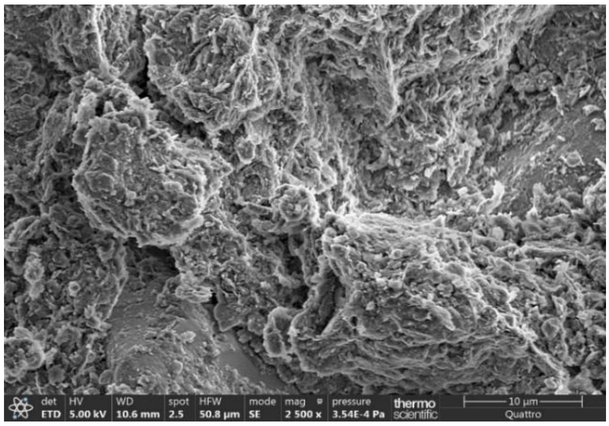

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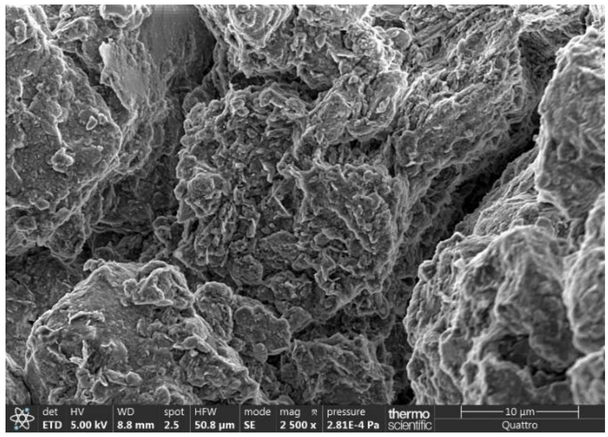

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Fig. 4. *SEM of compacted three sabkha soils: a - HSS, b - MSS, c - LSS*

Conclusion

The investigation into the effects of salinity on sebkha soils has yielded significant insights into their physical, mechanical, and chemical properties. The study reveals the following key findings:

- **Grain Size Distribution**: Higher salinity levels lead to a greater proportion of finer particles, with 70% of grains having diameters less than 60 µm. Specifically, low salinity soil (LSS) contains 19% more particles smaller than 20 µm compared to high salinity soil (HSS). This shift is attributed to the dissolution of larger aggregates in high salinity conditions, which increases the proportion of finer particles.
- **Stress-Strain Behavior**: Increased salinity results in more pronounced ductility and reduced peak strength. The unconfined compressive strength (UCS) decreases from 1100 kPa in LSS to 200 kPa in

HSS, while the peak strain at failure increases from 2.3% to 4.7%. This trend indicates that higher salinity softens the soil structure due to the dissolution of salt phases, disrupting soil cohesion.

- **Unconfined Compressive Strength (UCS)**: UCS decreases with increasing salinity, with values of 200 kPa for HSS, 580 kPa for medium salinity soil (MSS), and 1100 kPa for LSS. The maximum strain at failure also varies, showing higher strain in higher salinity soils. This reflects the impact of gypsum and halite on soil strength, with gypsum having a significant effect when salinity levels decrease.
- **Chemical Analysis**: The pH of the soil decreases with increasing salinity, indicating greater acidity. The pH shifts from 8.17 in LSS to 6.79 in HSS, highlighting the influence of chloride concentrations. The transition from high to low salinity also shows a shift towards a neutral pH environment.
- **Microstructural Analysis (SEM)**: Higher salinity soils exhibit a denser microstructure due to salt cementation. In contrast, lower salinity soils have a more porous structure with increased microporosity. The dissolution of salts under higher salinity leads to structural rearrangements, affecting soil strength and stability.

Future research should focus on developing comprehensive models that integrate the chemical, physical, and mechanical properties of saline soils. These models would enhance predictive capabilities, aiding in the design of effective soil management strategies. Additionally, understanding the effects of salinity on soil properties can inform remediation and stabilization techniques. Investigating methods to stabilize or improve saline soils with additives or treatments that counteract the negative impacts of salt dissolution could significantly enhance soil strength, cohesion, leading to more robust and sustainable management practices.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

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A TYPOLOGICAL IDENTIFICATION OF THE LARGE HOUSING ESTATES OF 1950S IN ORAN. EXPLORING THE THREE - DIMENSIONAL APPROACH

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Abstract: *In Algeria, the city of Oran is home to around fifty large housing estates built in the 1950s-1962, designed according to ethnic diversity, amalgamated location between the city center and the surrounding suburbs accompanied by facilities with a metropolitan influence, also known as modern housing estates, witnessed a revolutionary trend never seen before in Algerian society in particular, living in shantytowns. However, they suffer fierce criticism associated with their monotony and similar design, leading to their stigmatization and marginalization. This article aims to identify typological diversity across three dimensions, architectural, urban and social, using ethno-architectural analysis, comparing inhabited surveys, semi-directive interviews and photographs to highlight the particularity and typological characteristics of a sample of large housing estates in Oran. The results obtained by this study reveal that the typologies vary according to the dimensional criteria raised, highlighting their diversity and richness.*

Keywords: *large housing estates, typologies, three-dimensional, ethno-architectural, inhabitant.*

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Received: 30.08.2024

Revised: 07.10.2024

Accepted: 20.10.2024

Introduction

With the influx of labourers, followed by the further expansion of family immigration [1] and the rise in Algerian families 77.3%[1], the housing problem started to manifest in 1946. Consequently, the construction of housing for the majority was initiated in the suburbs of Oran [2], leading to the emergence of the *'large housing estates'* a novel model of social housing mandated in 1949 [3] to be implemented across metropolitan France and the French colonies. A chance emerged to transform the city of Oran into a contemporary metropolis, by transitioning from unsanitary and unstable housing to innovative and comfortable dwelling, in line with the prevailing societal movement of that era. An innovative architectural style and a vibrant social environment emerged between 1950 and 1962, culminating in a significant milestone in Algeria's colonial housing history. Conceptualized as self-governing municipalities with cultural, health, educational, and economic amenities [4], these towns often resulted from a crisis that required public policy intervention. They were mostly perceived as catalysts for social and cultural change [5], but in other cases, they were seen as catalysts for social and cultural transformation. Initially, these towns appeared unaffected by the political system, which is prevalent in Western democracies like France and Italy but is exported by the metropolis to Algeria [6]. The housing stock primarily consists of dwellings constructed in the adjacent suburbs for the two separate populations, with a small number located in the central city.

Contrary to what we are used to hearing about a test laboratory, the large housing estates were first initiated in the French metropolis, the country of origin, before finally arriving in Algerian soil, the country of importation [7], designed by world-renowned architects such as Pouillon Candilis and Simounet, specialists in social housing, who carried out large-scale housing projects in the major Algerian cities (Oran-

[1] DEMONTÈS Victor, L'Algérie économique: la population algérienne, t. 2, Algiers, Impr. algérienne, 1923, 498p. (based on data from Augustin Bernard's Enquête about habitation of algerian's indigènes (1921)); quoted by KATEB Kamel, Européens, "indigènes" et Juifs en Algérie..., op. cit., p.183).

Alger, Annaba), as well as major construction companies that were responsible for the territorial and technical development of several large housing estates, including the Algerian company Chauffour-Dumez and the Algerian company Léon Ballot, one of the factors that ensured the large-scale production of housing. The title of this period of cooperation is "The Algerian Saga" [8], the complexity of which is linked to the different contexts in which they were built [9].

However, from the 2000s onwards, fierce criticism seemed to be at its height, with all the large housing estates in Oran beginning to be seen as identical banal creations, the source of all the evils of society - delinquency, prostitution, theft, crime - a superficial and unscientific discourse that dragged on and stigmatized their development, or even delayed a possible heritage strategy, already envisaged in some cases overseas, witness to a social, urban and architectural history of a particular period that will not be repeated [10], an approach that illustrates this inscription of GEs in time [11]. The large housing estates in Oran are neither classified as heritage nor considered valuable architecture. This is due to the need to identify their diversity and uniqueness, some of which are hidden. This question raises concerns given its quantitative importance, which reaches 20% of the housing stock [12]. The vice-heritage approach has strengthened the protection of the architectural product as a whole, and the issue of conserving social housing is of greater concern to some agents of the architectural and heritage production space [13].

Through recent research into the future of this modern colonial architectural heritage, we want, using this article, to share the elements dissected to take account of the diversity of the four essential historical, social, urban and architectural dimensions, whose reflection on heritage should be given some limits based at least on its four headings [13]. Beyond the conclusions drawn from the typological diversity that we have gradually rediscovered through the ethno-architectural approach, the case study makes it possible to break with the criticisms of their repetitive monotony. A solid base of data has been developed to understand the concept of large Algerian housing estates better in order to make rational and objective decisions about their trajectory, which can be fulfilled and sustainable in the face of heritage approaches whose commitment begins first with identification, knowledge, protection, and enhancement [14].

In addition to proposing a reflection aimed at incorporating everyday, ordinary life into the heritage approach, this research on six large housing estates in Oran aims to alter the typically static perception of the banal, concealing immensely rich characteristics and activities... Reference [15]. The questions pertained to their relationship with their current residence and the modifications they had implemented before or during their relocation. The study residences were chosen using the quota sampling technique.

Materials and Methods

This research work is grounded on the empirical ethnoarchitectural approach, which allowed for direct field tests to confirm the previously formulated premise. Drawing on a representative sample of six exemplary large housing estates, volumetric, aesthetic, structural, and socially diverse features are examined despite variations in location within the city (city center/suburbs). An examination of the data acquired by an investigative instrument, including surveys, semi-structured interviews as the primary data gathering method, specifically intended to investigate responses to indirect enquiries [16], and images of exteriors, collectively known as "ethno-architectural surveys". This survey is a method that enables data collection with a quite reasonable degree of validity [17]. During the field study, criteria and sub-criteria were developed and organized into a typology to define the main geographical areas. Table 1 displays the primary criteria and sub-criteria for each dimension to determine the typologies of the large housing estates. It demonstrates their uniqueness, which aligns with an architectural component and a wider societal rationale [18] that can be considered a national legacy, seen as a contextual architectural heritage that fuses modern architecture with local architecture in large Muslim housing estates.

Table 1. Criteria and sub-criteria for large housing estates typologies (source: authors, 2023)

Architectural dimension	**Urban dimension**	**Social dimension**
The location of spaces (served, serving)	Perception	Dynamic social environment
		Daily activities such as the market
		religious festivals
Conviviality	layout	Income level
Defined surfaces	Size and shape	Education level
Degree of transformation		
Access to dwellings	Mode of access	Category of communal areas appropriation
		Behaviour
		Sociability
Window types	Number of dwellings	*Original inhabitants*

We are currently observing the third generation of residents in the various large estates, with a notable predominance of young residents aged 28, representing 50% of the sample, and middle-aged people up to 45, who make up 35%. Those aged 70 and over make up a smaller proportion, at 15%. The field survey included perspectives from all three generations (older people, adults and teenagers). It ensured balanced representation between genders (male/female) and between tenants and homeowners during the semi-structured interviews, which were organized at the time of the cell surveys and at the time of the national religious holidays, which began with key questions combined with secondary questions in order to clarify the purpose of the interview [19].

Case study

Oran has a strong identity, reflected in its rich and diverse architectural heritage. These traces of the past help to make Oran a modern city: Oran, on the contrary, is a city without suspicion, in other words, a completely modern city [20]. The large housing estates of the 1950s were created with the help of several project managers, a harmonization that bears eloquent witness to the joint efforts of these personalities. The work of locating and identifying the initial corpus of large housing estates from 1950-1962 is an essential stage that precedes the phase of selecting and analyzing large housing estates for a diversified typological identification (Table 2). To this end, two waves of large housing estate construction have been identified, showing the richness of their diversity.

The first wave (1950-1958) was marked by the architectural richness and monumentality of the large complexes, with conceptual variations in the flats depending on their purpose (Muslim, European). The complexes of this first phase also came closest to the principles postulated by the architects of the Athens Charter in 1933, with the integration of elements that "make up" modern comfort.

The second wave (1958-1962) was clearly marked by the sobriety and informality of the façades. This period coincided with the adoption of the "Constantine plan", when the effort was multiplied with singular creations by universally recognized masterpieces (Fig.1).

Table 2. Identification sheet for the six main case studies

Large housing estates	L.H.E 1	L.H.E2	L.H.E3	L.H.E4	L.H.E5	L.H.E6
Year of construction	1951-1957	1957	1956-1958	1955-156	1959	1954-1956
Architect	Pierre Jean Guth	Justin Marie	Henri Désiré Cantie	Justin Marie	Jean Bedeau Andre Gomis V.Mialy D.Roman	Fernand Pouillon
Owner	HLM company	Algerian Cooperative Society for Muslim Housing	Municipal Housing Office HLM	Algerian Cooperative Society for Muslim Housing	C.I.A[2] for C.I.LO.F[3]	HLM company
Housing category	H.L.M improved	Semi-urbain[4]	Million	Semi-urbain	Million[5]	H.L.M improved
Number of dwellings	580	376	602	254	520	614
Destination	Marine officers + civilian civil servants + workers from mainland France	Resettlement scheme for tenants of buildings in danger of collapse in the navy district	French social class	Algerian Muslims	Civil servants	Naval staff


1 L.H.E Dar Beida


2 L.H.E Sid el houari


3L.H.E Lescure


4 L.H.E la quiétude


5 L.H.E les falaises


6L.H.E Valmy

Fig. 1. *Photographic images of the six large housing estates of the case study (source: authors + Oran archive)*

[2] Algerian real estate financing.
[3] Housing company for civil servants.
[4] Semi-urban' housing, specific to Algeria, was introduced at the end of the decade. This was a "much simpler type (...) designed to provide a decent flat for those living in the casbahs or gourbis with limited resources" Guillopé. 2023, p. 516.
[5] The so-called "million-franc" housing scheme, envisaged from the summer of 1954, was introduced in November 2. Expected to cost one million francs, it was designed as an intermediate range between the Logécos, which many people found too expensive, and the "basic economic housing" (LEPN), also known as "standard economic housing". Decree no. 54-1120 of 10 November 1954 (JORF-LD, 16 November 1954, p. 10793; see also the opinion of the Economic Council in its meeting of 8 March 1955, reproduced in the appendix dedicated to Regulatory Texts.

Results and Discussion

Spatial configurations on an urban scale (recurring mass layouts)

The compositional analysis of the ground plans in our corpus reveals three recurring typologies that have been attempted in this selection. These typologies are focused on the criteria of orientations described as guiding principles of the ground plan and the layout, distribution, and assembly of these plans to the extent that they exhibit variations.

The Tower and bar model

This model is very much in line with the standard definition and the image that immediately springs to mind for these housing developments built in France. Comprising low-rise blocks and a tower of over 17 storeys with bars, the ensemble forms a central island affected by an internal courtyard. The designers propose to open up panoramic views towards the immediate environment from the volumes created; this large-scale composition has made it possible to acquire the maximum number of dwellings known as the "million operations" which is the size of the large-scale operation comprising 500 to 600 dwellings. The orientation of this typology is identical, most often N/S or E/W (Fig.2).

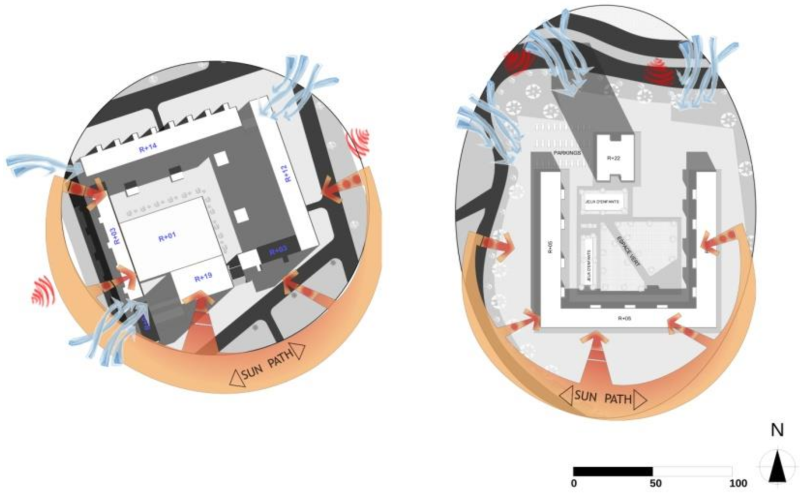

Fig. 2. *The mass plans of the Tower and bar model Lescure+Les falaises (authors, 2023)*

The pavilion model

The pavilion model accounted for a significant portion of our corpus (60%), comprising a sequence of bars with identical shapes that ran parallel or perpendicular to each other and varied in orientation. This resulted in an expansion of the range of house designs implemented. These developments are of medium to large scale, often consisting of 200 to 600 houses, with the concept occasionally integrated into some of the bigger compositions. Since the direction of the different low-rise blocks (R+5) and their distance around each other result in very low or nonexistent masking effects, the sunshine factor was a genuine worry. Thus, this design deviates significantly from the conventional design of major developments, which involves different orientations for all the buildings and a maximum of 2 or 3 "typical" structures of the same height and surface area that would be replicated to form the project (Fig.3).

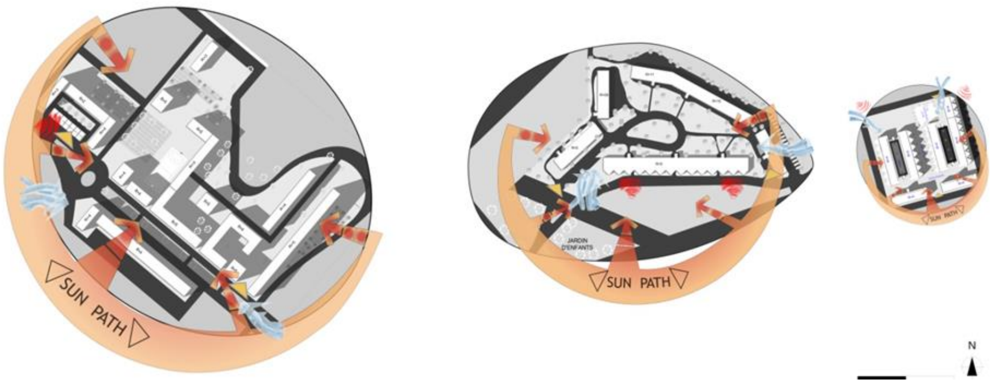

Fig. 3. *The mass plans of the pavilion model Valmy +Sid el Houari+La quietude (authors, 2023)*

The Hybrid model

The Hybrid model comprises a centrally situated huge structure, including a tower affixed to a long, curved bar, with equipment injected into the surrounding area from opposite sides of the plot. Three identical bars have been positioned at a locus in the northeastern direction. The northern side strip consists of two 4-storey structures strategically positioned to face about north and south, thereby maximizing the advantages of the winter sun and the summer sea wind (Fig.4).

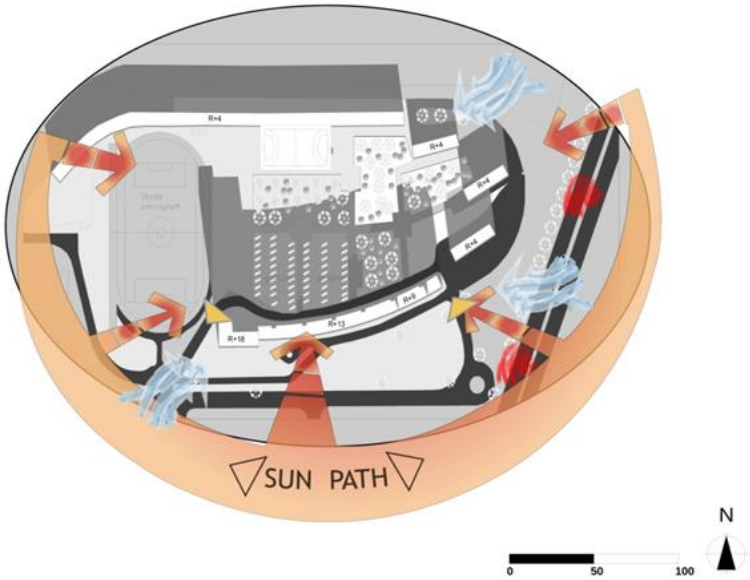

Fig. 4. *The mass plan of the hybrid model of Dar el Beida (authors, 2023)*

Spatial configurations on an architectural scale (plan of recurring dwellings)

The "Semiramis" plan[6]

This typology has found wide expression in Oran [21]. The characteristics of this type of flat are linked first and foremost to local requirements, as it was designed for the conservative indigenous population. Access to the different flats is via the corridor. The principle organization of the flat plan places the service spaces directly at the entrance. It pushes the service spaces to the rear, where the circulation spaces of Semiramis are less visually exposed, and the high walls preserve the inhabitants' privacy to a greater extent [22]. Unlike the spatial distribution of the concentric open-air courtyard found in the traditional Muslim house, this typology provides for separating the courtyard from the other spaces, thus losing its traditional organizational and structural role. The windows have been drilled into the walls on a reduced scale to maintain privacy and allow people to see without being seen (Fig.5).

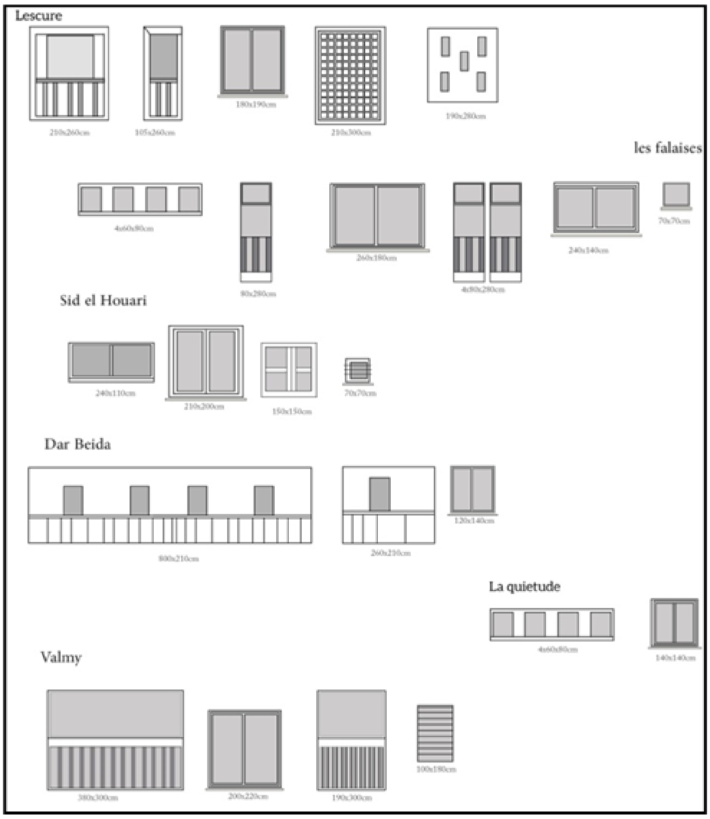

Fig. 5. *Survey of type of windows for each case study. Oran (authors, 2023)*

This type of housing, therefore, corresponds well to the desired objective: to provide affordable housing with a high level of modernity and comfort so as not to create a financial imbalance for the head of the family. The surface areas are identical in the two programmers', 2 and 3 rooms in the majority (T2=36.81m^2,

[6] Conceived by architect George Candilis, this is a model of social housing specifically created for the Algerian and Morocco people. It maintains a formal architectural layout resembling a tripod with pathways and incorporates a traditional courtyard at the back of the residence. The serviced areas are prominently displayed in large sizes.

T3=48.87m², T4=65.87m²), all of which face both sides of the building, so they benefit from a dual orientation that allows them to receive maximum light and sunlight. A single architect's design of identical accommodation for two different housing estates with the same purpose does not inspire any transformation or modification[7] (Fig.6).

Fig. 6. *Survey of a dwelling T2, T3, T4 of Sid el Houari and la Quietude. Oran (authors, 2023)*

Logécos plan[8]

This is a typology that first existed in the French metropolis and was transported to Algerian soil, keeping the same dwelling surface areas[9] T3 = from 48 to 67 m², 4P = from 53 to 68m, established by a decree of 16 March 1953 "Dwellings must have electric lighting and equipment, including at least an installed shower, a sink and a washbasin, WCs must be installed inside the dwelling; possible derogations (absence of existing technical networks" [23]. This type includes the large Lescure and Les Falaises developments, which were designed in an era of technical modernization but also with hygiene in mind [24]. Housing of the "economical and family" type will enjoy all modern conveniences and benefits from dual orientation. The living rooms face south and west and are magnificently exposed, while the kitchen is equipped with a drying rack to protect it from the sun, separate from the living room. The walls of the facades are made of white ashlar, pierced by large picture windows, a symbol of openness (Fig. 5). However, investigations and surveys have revealed two types of modification: additions to the landing and extensions to the kitchen, removing the drying room to acquire a few extra square meters. The second is the introduction of new interior spaces by adding partitions, given that the space is large. These two types of action, the first one privileges to exploit wasted space, while the second involves the independence of each space (Fig.7).

[7] The observations and interviews carried out in 2023 for this type of housing reveal no major changes to the housing, which results from a development designed to meet the needs and lifestyle of the local population from the outset.

[8] Economic and family, it is a type of housing managed by a low-rent housing organization (HLM), public or private, that benefits from partial public funding, direct (subsidy) or indirect, Dictionary la rousse2015 .la petite "economic" property ("Logécos" formula).

[9] Inter-ministerial order of 17 March 1953, art. 5 (JORF-LD, 18 March 1953, p. 2562).

Fig. 7. *Survey of a dwelling T3, of Lescure and Les falaises Oran (authors, 2023)*

Improved HLM plan

Pouillon is a prime example of this. In the Valmy housing estate, intended for the families of naval personnel on duty at the Lartigue naval air station, the flats have 1-5 rooms plus a kitchen, toilet and shower room. They all have a double aspect based on a North-East, North-West / South-East, South-West layout. The "day" and "night" areas are also clearly separated, with the living area first and the dining area at the back of the home. Adding a bedroom to the living room means we can choose between an extra bedroom or a larger living room. This housing configuration aims to offer households freedom in the layout of their homes. This is an example of an innovative architectural concept, reflected in the "flexibility to modify" of the plans, enabling flats to be converted, enlarged or reduced in size in the future without having to undergo major alterations. Despite the same purpose, the spatial distribution is well thought out and nuanced (Fig.8). No changes were made to the accommodation in these two housing estates, given the generosity of the space and the modern comforts.

Fig. 8. *Survey of a dwelling T3, T4 of Dar Beida and Valmy. Oran (authors, 2023)*

Spatial configurations on a social scale (the expression of inhabitants)

Based on interviews with residents and two years of observations, a proposal has been made for a social typology about the different areas of the large housing estates, broken down into three categories:

Discreet social housing

Discreet social housing includes the two major housing estates, Valmy and Dar el Beida (Fig.9), which are now inhabited by non-sedentary military families who are not native to the city of Oran. 80% of the interviewed population reported that the residents' experience is characterized by secrecy: "We cohabit but remain not acquainted with one other; this is due to the state's responsibility for the upkeep and administration of the large housing estate". They intend to depart for their extended family outside Oran during religious holidays. Veschambre argue that the appropriation of housing is associated with identity and symbolism, characterized by its tangible, consistent, and demonstrative implementation manner [25].

Fig. 9. *Communal spaces in the two large housing estates (Valmy, Dar Beida) (authors, 2023, 7 p.m.)*

Intense social housing

Lescure, la quietude, and Les Falaises housing estates are characterized by a vibrant and lively social life, which is highly valued for its distinctive influence on the intellectual development of the residents. The primary factor that led to the development of this typology is the significance of identity within the cohabitation of various categories of inhabitants who contribute to the formation of diverse values in acquiring and utilising shared areas. "We can see that the relationship between societies and their spaces, places, and territories has a strong identity dimension", Di Méo[10] observes (Table 3).

Table 3. Summary table of the survey carried out at the three locations (authors, 2024)

Criteria / Large housing estates	Dynamic social life	Income level	Level of education	Type of appropriation of communal spaces	Original inhabitants
Lescure	Strong	Low	Medium	Singular	70%
Les falaises	Strong	High	High	Authentic	85%
La quiétude	Strong	Low	Low	Modest	95%

The courtyards in the three large housing estates embody a unique act of appropriation by the inhabitants. This co-ownership IU enhances the reputation of the estates by fostering a positive utilization of the space and promoting a vibrant social life. This is evident not only daily but also during religious festivals when the courtyards serve as exceptional venues for appropriation (Fig.10). Most of the interviewed residents originate from the expansive housing estates, which have existed since the 1960s-1970s, following the departure of the French social class. However, a few residents of the quiet area have continued to live on the premises even after gaining independence. This can be attributed to their relatively low income and level of education, as is characteristic of the native population. Conversely, on the cliffs, many residents are productive farmers with a substantial income, which is seen in the genuine use of the community spaces[11].

[10] DI MÉO, Guy. L'identité: une médiation essentielle du rapport espace/société. *Géocarrefour*, 2002, p. 175.
[11] In 2022, the wali of Oran redecomposed LES FALAISES as the most robust and well-preserved huge ensemble in Oran.

Fig. 10. *Common spaces in the three main areas during festive religious events (Lescure, les falaises, La quietude) (authors, 2023)*

The social ghost

The observed and investigated realities reveal a typology of a large housing estate devoid of vitality and liveliness. This typology is not only influenced by its location in the old Oran (formerly a shanty town) with insufficient facilities and a cemetery that serves as an obstacle facing the large housing estate (Fig.11). Additionally, 70% of the interviewed residents do not hail from this area, resulting in a lack of identity value, nostalgia, and militancy. Consequently, the absence of appropriation of the various common spaces can be justified.

"*I have recently relocated to Oran, where I work and spend my days outdoors, so I am unfamiliar with the residents. The area is tranquil, with everyone confined to their peaceful residences. Even during periods of weakness, I choose not to venture outside to prevent potential conflicts with the inhabitants*". Extract from an interview with a 36-year-old male resident of Mascara town.

The absence of recreational spaces, street furniture, and diverse landscape elements, such as trees, vegetation, and tiny squares, elucidates the lack of vitality in SID el Houari, mirroring the loss of spirit among its inhabitants.

"Regrettably, our former residents, who were single families, have left this large housing estate, which met the standards of social diversity, justice, citizenship, equality, and solidarity. New arrivals value this type of housing more than residents born in the complex. I intend to maintain a pristine appearance, particularly in the courtyard where we interact socially". Extract from an interview with a 71-year-old man.

The analysis of the three-dimensionality of the six major housing estates revealed the identification of three distinct typologies of these estates based on clearly established criteria. The data collecting approach we will employ is "ethno-architectural surveys". Including urban typologies characterized by their size, shape, purpose, and number of residents, it is evident that the shapes were mostly varied by the tower block and bar type, facilitating the integration of green areas. Ultimately, various models that were preferred by the political figures of that era, namely the diverse project owners, extended outside the HLM office. Two other models were proposed: the pavillonnaire, characterized as an unstructured open urban model, and the hybrid model, which integrates the above-described models with a balanced urban layout and includes many amenities. A reimagined version of the traditional house, with the courtyard patio as the key organizational element, the "Semiramis" style is designed for the conservative Algerian populace, whose spaces are somewhat limited. The Logécos "economic family" low-cost housing model has surface areas that precisely match those of the metropolitan low-cost housing model. All three- and four-bedroom flats in this model are designed with a double orientation to ensure optimal sunlight exposure for the dwellings. In the spatial dwelling, an enhanced low-cost housing concept created by famous architects for navy personnel and their families, the east-facing bedrooms receive morning light. At the same time, the living spaces get maximum sunlight during the middle of the day. Conducting a comparative analysis of the facades has enabled the determination of the number of bay models associated with the intended use of the extensive complex. Within Muslim housing, the typical number of windows per project ranges from 2 to 4. Several expansive home developments within European housing, such as les Falaises, Valmy, and Lescure, feature a range of 3 to 6 distinct types of openings.

Fig. 11. *Common space in the large housing estate of Sid el Houari (authors, 2023, 11 a.m.)*

The extensive housing development's social structure was an essential factor in comprehending and analyzing it. Three social typologies, characterized by varying degrees of apparitional, discreetness, and liveliness, were identified. These typologies were examined based on how both native inhabitants and newcomers appropriated communal places.

Conclusion

Additionally, this study enabled the creation of typologies for large housing estates that go beyond the typical towers and bars commonly associated with them [26]. Contrary to popular belief, large housing estates are not uniform and standard but rather distinct from one another, shaped by the cultural background of the architect who designed them and by particular societal logic with diverse profiles (native, European, working class, etc.). In other words, these estates are architecturally tailored to the intended population, influenced by the introduction and inspiration of new ideas. A prime example is the "Semiramis" design, initially conceived by the architect Candilis in Morocco, drawing inspiration from the architect Justin Marie. It serves as a reflection and is an excellent example of modern architecture adapted to the local context. A comprehensive examination of the activities at the urban master plan level has allowed us to comprehend better the incentives and mechanisms implemented and the selection of building orientations, prioritizing solar gain for the whole building envelope. The diverse floor designs, characterized by their different sizes and shapes, rendered each project a distinct phenomenon. These tools are used to strategically design a well-defined area tailored to the operation's scale and function to establish a cohesive urban structure that aligns with the ideals of the contemporary movement.

Ultimately, considering the meticulous observations and extensive conversations with residents, it becomes evident that the social impact is unique across all major housing complexes. Some of the changes and positive appropriations made by the residents are highly intense, and their sociability plays a crucial role in establishing and sustaining the social impact. This highlights the development of a heritage, particularly through the appropriation of the space and the existing social practices. The non-sedentary population influences the discreteness of the premises. It can be observed that a majority of tenants dominate the social dimension, resulting in disrupted and less anticipated appropriations and sociability. Consequently, this directly affects the original social aspect of the large housing estates. Finally, the social ghost, characterized by its geographical position, has become a distinct social enclave and significant housing estate, isolated from the rest of the city. However, nowadays, the major housing estates in the suburbs have become fully integrated into the urban structure of the new city, except for those in the Intramuros. Consequently, many of its residents have left the area and been replaced by non-Oranians seeking employment in the big city.

Acknowledgements

The authors acknowledge the PAVE laboratory and the ERMAM laboratory for their support for the short-term mobility programme. The authors would also like to thank Fanny Gerbaud, lecturer and researcher at National Higher School of Architecture and Landscape in Bordeaux, who assisted in data collection and organising the conference. We would like to thank the members of the national archives of Algiers and Oran for providing access to background information.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This work was supported by the Research Laboratory of Metropole Architecture Urbanisme Societé LAMAUS at USTO-MB. Oran.

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SMART AND DYNAMIC FACADES: A PATH TO ENERGY OPTIMIZATION IN ARID ENVIRONMENTS

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Abstract: *The modern movement of architecture has led to a proliferation of buildings featuring transparent facades, which unfortunately amplify the energy needs of these structures. Mitigating this energy consumption necessitates a reevaluation of architectural strategies. Addressing concerns such as overheating, innovative solutions like smart and dynamic double-skin facades have emerged to curtail energy usage while ensuring comfortable indoor conditions. This study focuses on examining the efficacy of smart facades, employing electrochromic glazing, and dynamic double-skin facades, and integrating dynamic shading systems, in reducing energy consumption within office buildings located in hot and arid regions. Parametric simulations were used on a particular office building, comparing scenarios with and without the implementation of smart and dynamic double-skin facades, particularly on south-facing orientations. The simulations varied the wall-to-window ratio (WWR) to gauge energy performance under different configurations. Furthermore, multi-objective optimization (MOO) techniques were employed to analyze and optimize shading device properties. Parameters such as depth, distance from the glass, shade angle, and spacing between shades were optimized as genetic variables to determine the most energy-efficient configuration for office buildings. The study results demonstrate that the use of EC glazing is beneficial in all WWR percentages, achieving 67.65% of energy saving in 90% of WWR., Also it was found that the optimal solution for saving energy is using DDSF with 20 cm of shading depth, 45° of shading angle, and double low-E vacuum in the inner skin, with an energy saving of 70.32% in the case of 90% of WWR compared to the base case.*

Keywords: *smart façade, dynamic double-skin façade, energy consumption, parametric simulation, office building, multi-objective optimization (MOO).*

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Received: 10.08.2024
Revised: 22.09.2024
Accepted: 24.10.2024

Introduction

In the built environment, the focus on sustainable development principles has generated considerable research interest in enhancing the efficiency of building skin. Façades, as integral components of construction envelopes, play a crucial role in safeguarding indoor ambiances and regulating the interaction between outside and inside spaces. Advancements in building technology have facilitated the development of various types of dynamic building elements, aiming to achieve higher levels of sustainability and aesthetics [1,2]. Promising areas of development in adaptive technologies such as phase change materials [3], adaptive solar shading [4], multifunctional facades [5], switchable glazing [6], and double-skin facades (DSF) [7] have been identified. In this research, our focus will be on switchable glazing and dynamic double-skin facades (DSF).

Switchable Devices

Switchable materials, categorized as smart materials, possess the capability to independently and reversibly change color. This change occurs as a result of reduction or oxidation reactions triggered by an electrical stimulus.

Classification of Switchable Glazing

The categorization of switchable glazing systems into active or passive is dependent on their functioning [8]. The passive systems operate independently, reacting to natural excitations such as heat or light without requiring external input. Examples of passive systems include photochromic (PC) glazing [9], thermochromic (TC) glazing [10], photo-electrochromic devices (PECDs) [11], and photovoltachromic (PVC) glazing [12].

In contrast, active systems have the capability to react to an exterior electrical stimulation by adjusting their optical properties. They can adapt to changes in both internal and external environmental conditions, thereby meeting the demands of the user. Examples of active systems include electrochromic (EC) glazing [13], gasochromic glazing [14], suspended particle devices (SPD) [15], and liquid crystal devices (LC) [16].

The focal point of this study revolves around EC windows, which can be likened to electrical batteries. Typically, these windows consist of five stacked layers positioned between plastic substrates or two glasses. These layers are covered in invisible conductive oxides., such as indium tin oxide or fluorine-doped tin oxide. Among these layers, the middle one acts as a transparent electrolyte that is filled with hydrogen or lithium ions, which are small cations. It directly interfaces with at least one EC material and either an ion accumulation layer or another EC layer [17,18]. Inorganic transformation metal oxides, such as nickel oxide (NiO) or tungsten trioxide (WO3), are among the most extensively studied EC materials (Fig.1).

Electrochromic (EC) glazing available on the market exhibits a blue tint, largely attributed to the common use of tungsten trioxide (WO3) as the electrochromic material. This material enables an alternation of transparency, transitioning from clear or bleached (device off) to dark or tinted (device on). In terms of performance metrics, the Solar Heat Gain Coefficient (SHGC) of electrochromic glazing usually ranges from 0.49 in the fully bleached state to 0.09 when completely colored. Additionally, light transmission values (VLT) can vary significantly, with a range from 69% in the clear state to as low as 1% when fully tinted.

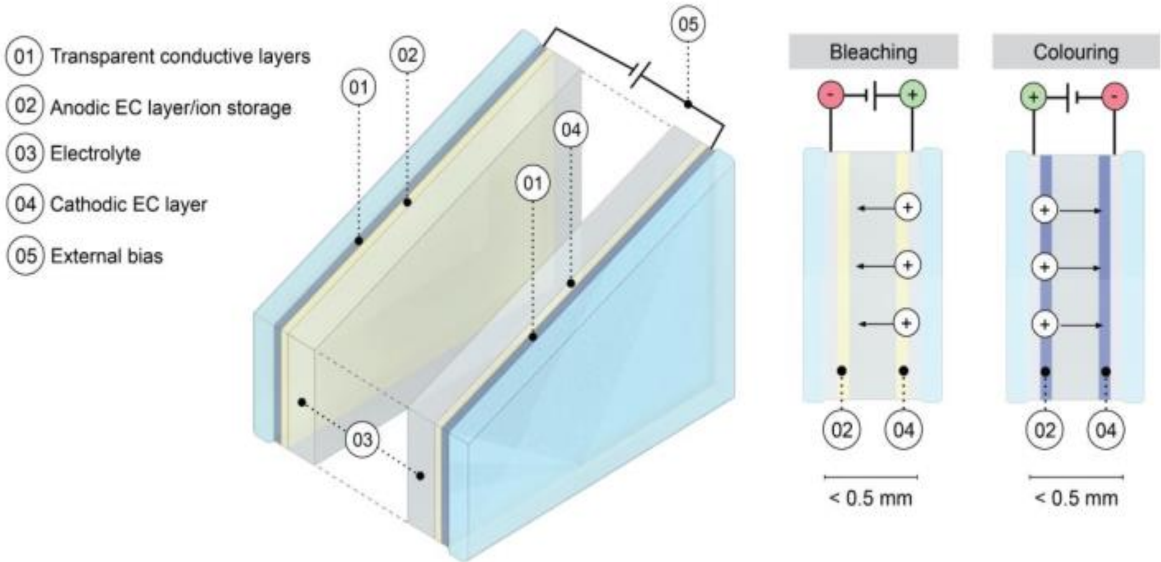


Fig. 1. *EC glazing schematic diagram [19]*

Double-skin facades (DSF)

Double-skin façade is a special type of envelope, where a second "skin", usually a transparent glazing, is placed in front of a regular building façade" [20]. Double-skin facade (DSF) is a façade of the building that spans one or more storey and consists of different glazed layers divided by an air gap. A defining characteristic of DSFs is their controllable shading system and the ability to facilitate airflow due to the cavity in such façade system.

The air gap between the two layers plays the role of an insulation barrier, effectively mitigating undesirable effects such as heat transfer or temperature fluctuations.

Classification of DSFs

Double-skin facades (DSFs) typically encompass multiple levels of a building and feature multiple layers, and they are generally categorized as either air-tight or ventilated [21]. Additionally, DSF typologies are classified based on their ventilation strategies within the cavity [22].

Air-tightened DSFs prioritize thermal insulation, particularly beneficial during winter months. In contrast, ventilated DSFs leverage sunlight to receive heat energy while reducing heat gain during summer [21]. These distinctions highlight the varying thermal performance and energy efficiency characteristics of DSF designs, tailored to different climatic conditions and seasonal requirements.

DSFs are classified based on four conditions: "window ventilation", "closed", "natural convection to outside", and "mechanical exhaust". Additionally, they are categorized according to their level of skin coverage, such as "window", "storey", or "multiple storey" [23,24]. Furthermore, researchers categorize DSFs into various types, including box window facades, shaft-box facades, corridor facades, and multi-storey facades [25,26].

The fundamental aspect of DSF conception is airflow management. The airflow patterns in DSFs vary depending on seasonal climates, as shown in Figure 2.

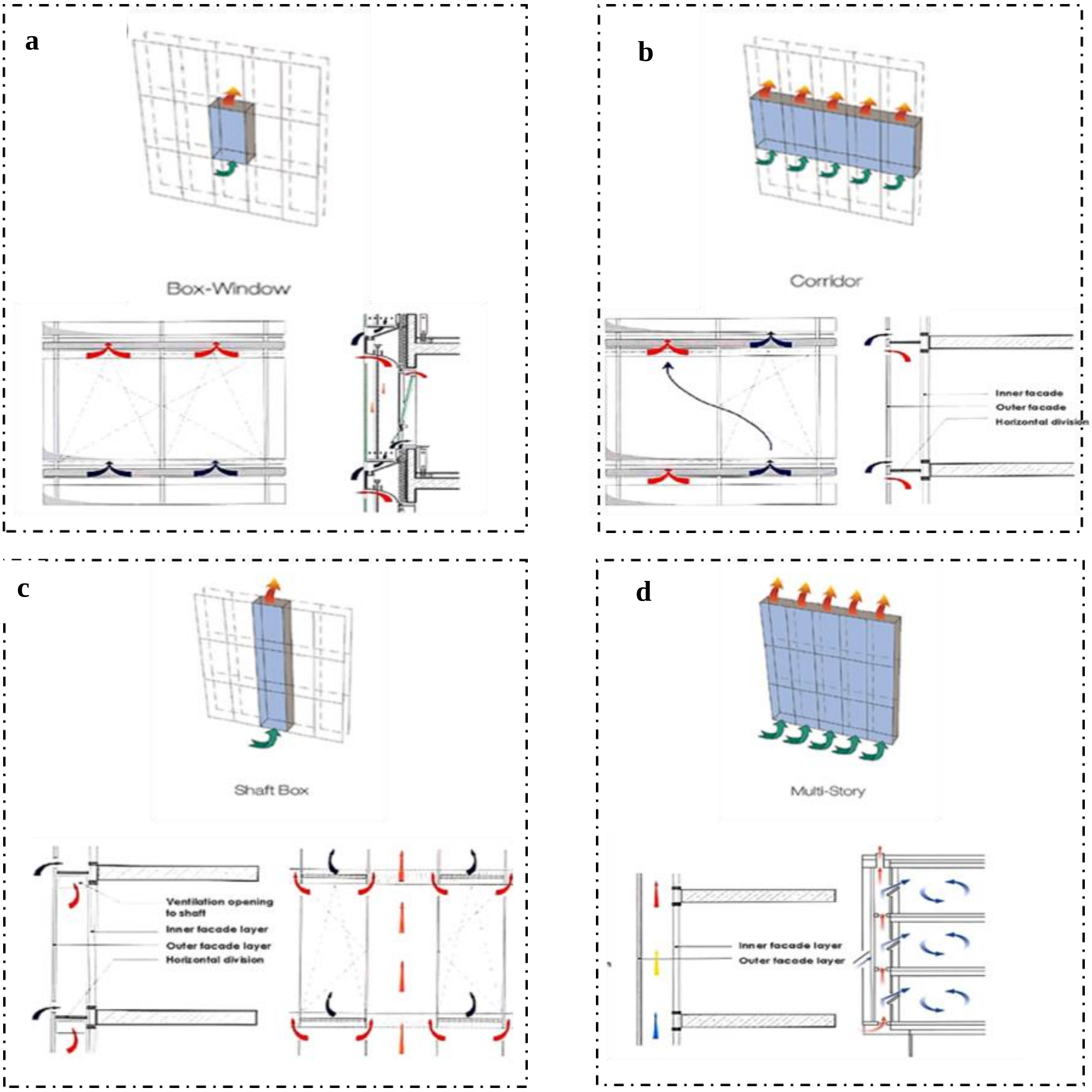


Fig. 2. *Different DSFs configurations.* **a.** *box window configuration*, **b.** *corridor configuration*, **c.** *shaft box configuration*, **d.** *Multi-storey configuration [27,28]*

Mechanism

The primary mechanism and associated energy balance are indeed crucial aspects of a double-skin facade (DSF) system. DSFs rely on natural ventilation technology, utilizing the solar chimney effect to facilitate airflow and regulate heat transfer. It's important to highlight the system's heat transport and airflow phenomena, as illustrated in Figure 3. This diagram likely demonstrates the convective airflow patterns driven by temperature and solar radiation differentials between the exterior and interior layers of the DSF. Understanding these phenomena is vital for optimizing the performance and energy efficiency of DSF designs.

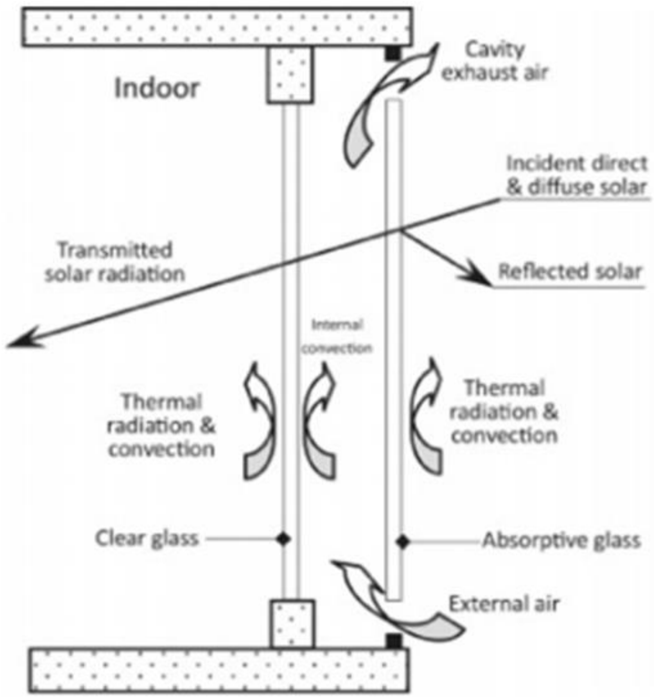


Fig. 3. *Heat transfer and airflow of natural ventilated DSF system [29]*

To understand the thermal reaction of the double-skin facade (DSF) system, several areas of heat transfer play significant roles: convection, conduction, and radiation. A sufficient temperature differential over the exterior skin triggers the stack effect. This phenomenon draws air upward in the cavity of DSF, effectively exhausting solar or building heat gains out the top. Moreover, wind pressure distributions at openings and exterior facades can impact the airflow rate through the cavity.

Transparent DSFs commonly incorporate shading systems in the cavities to mitigate solar heat gain and glare during the warmer season. However, the efficiency of these shading devices is contingent upon their orientation related to the azimuth and solar altitude and form for the specific period.

The performance of double-skin facades (DSFs) varies significantly across different climates. In cold climates, DSFs function as heat exchangers, working to maintain the temperature of the internal skin layer close to the desired indoor temperature [30]. On the other hand, in hot climates, DSFs can contribute to a low shading coefficient [30]. This indicates that DSFs can effectively reduce solar heat gain and mitigate thermal discomfort in warm weather conditions.

Literature review

Various research studies emphasize the significance of smart windows, such as electrochromic (EC) glazing, and dynamic double-skin facades, in different window-to-wall ratio (WWR) configurations for enhancing the energy performance of buildings. A study conducted by Sibilio et al. [31] concluded, in their review paper focusing on smart windows for residential applications, that the utilization of EC glazing can lead to energy savings ranging from 9% to 59% compared to conventional static glazing. However, the extent of energy conservation depends on different parameters, such as climatic conditions, control strategies, and building orientation.

Another research study, as documented in [32], conducted an investigation on the performance of electrochromic (EC) window prototypes using a full-scale office experimental setup. The findings of this study revealed significant energy savings of up to 59% when compared with classic windows.

In 2009, Rudolph et al. conducted a study on electrochromic (EC) glazing systems in collaboration with the California Energy Commission [33]. The study highlighted a notable 44% reduction in energy consumption used for lighting compared to a base case without daylighting strategies. Additionally, the study observed a reduction in window cooling loads, with peak demand decreasing from 26% to 19% on clear sunny days.

A study conducted using the eQuest building simulation tool [34] examined three distinct climate zones in the United States. The research focused on a commercial office building with a window-to-wall ratio (WWR) of 60%, comparing the efficiency of static glazing with electrochromic (EC) glazing. The findings revealed energy savings of up to 45% across different climate zones.

In another study [35], a simulation was undertaken to assess the lighting energy-saving potential of an electrochromic (EC) window. The performance in a south-facing office was simulated using two separated EC windows, approximately a 48% of reduction in energy consumption was observed compared to simple glass.

In another study [36], which utilized EnergyPlus dynamic simulation software, an investigation was conducted in an office building situated in Milan. The objective was to identify the best glazing type among the three of them (EC glazing, standard glass, and glass with an exterior Venetian blind system) in comparison to the standard glazing type. As a consequence, the results demonstrated that EC glazing minimize 39.5% of energy consumption, whereas the use of an external Venetian blind device led to a reduction of 26.2%.

The potential applicability of a double-skin facade (DSF) was investigated in [37] through the optimization of the relationship between window-to-wall ratio (WWR), shading coefficient (SC), and envelope thermal transfer value (ETTV) of a building.

The study revealed that an increase of WWR (0.9) reduces a DSF's ability to prevent solar heat gain. Conversely, the decrease of WWR (0.3) minimizes significantly the ETTV, about 45%.

Moreover, the increase of the shading coefficient (SC) from 0.3 to 0.7 of the interior glass increases the ETTV from 18W/m² to 59.6W/m². This relation indicates the importance of finding an ideal balance between ETTV and SC for a specified WWR, suggesting that different combinations of these parameters can affect the overall efficiency of a DSF system.

In another study [38], the energy performance potential of photovoltaic double-skin facades (PV.DSF) was evaluated. The study simulated the performance of PV.DSF in a south-facing office in a humid subtropical climate zone in Changsha, China.

During winter conditions, with a 12°C temperature differential between the DSF and external temperature, the ideal operating angle was determined to be between 10 and 20 degrees. During summer, wall temperatures and air were minimized by 0.5°C and 2°C, respectively, leading to a 10% reduction in cooling energy consumption. The optimal operating angle during summer was determined to be 30 degrees.

For intermediate conditions, when the DSF was open, the difference in temperature between the DSF and the exterior environment was less than 3°C. The optimal operating angle remained at 30 degrees during these intermediate conditions.

In 2020, M. Shakouri et al. [39] conducted a study on double-skin facades (DSF) with photovoltaic (PV) systems under Tehran, Iran's climate conditions, focusing on an office building with a south-facing orientation. The study reported significant annual reductions in energy consumption used for cooling and heating, amounting to 251,623 kWh and 17,811 kWh, respectively. Additionally, the PV system, with 10.6 kW as peak power, was found to produce approximately 18,064 kWh of grid-connected electricity annually. This implementation resulted in an impressive improvement in the energy efficiency index of the building, achieving a reduction of 34.3%.

In the context of Changsha, China (HSCW zone) [40], it was discovered that increasing the slat angle in a box-window double-skin facade (DSF) led to a decrease in the temperature of the inner glazing. The airflow rate exhibited a reduction when the slat angle ranged from 0 to 60 degrees. However, when the slat angle exceeded 60 degrees, the airflow rate increased. This observation pertained to a naturally ventilated cavity.

On a related note, [41] investigated the impact of changing the tilt angle of blinds between 0 and 90 degrees across three different controlled ventilation rates (200, 400, and 600 m^3/h). They found that adjusting the tilt angle of blinds resulted in a decrease of the inside interior glass temperature as the tilt angle increased, especially with high ventilation flow rate, in the case of a box-window DSF.

In the study conducted by [42], a south-oriented multi-storey double-glazed facade (DSF) with both horizontal (90-degree angle) and vertical (45-degree angle) louvers was evaluated to enhance natural airflow in office buildings in Isfahan, Iran. The CFD (computational fluid dynamics) technique software was employed for this evaluation using ANSYS.

It was observed that the buoyancy forces of the DSF equipped with horizontal louvers in the cavity were stronger, resulting in a higher ventilation rate compared to the model with vertical louvers. Furthermore, the cavity with horizontal louvers had a larger heat flux on the inner glass than the cavity with vertical louvers, owing to enhanced convective flow. As a result, heat from the cavity is transferred to the occupied pieces via the internal skin. On the contrary, in vertical louvers, the heat flux from interior glass was low, nearly zero, related to the obstruction of sun radiation.

Interestingly, other researchers have also supported the notion that for multi-storey DSFs, positioning louvers closer to the outer layer allows for sufficient airflow on both sides while maintaining an adequate distance from the interior glass [43].

As evidenced by previous studies, the energy efficiency of buildings is affected by a multitude of interactive parameters. This underscores the necessity of adopting a parametric approach to accurately model building behavior, considering the dynamic interplay among these factors.

However, despite the extensive research in this field, there remains a significant gap concerning the impact of utilizing smart and dynamic double-skin facade (DSF) systems in Algeria, particularly in office building located in hot, arid regions. Addressing this gap was the primary focus of the present study. By concentrating on this specific context, the research intended to provide significant insights into the potential advantages and challenges associated with implementing smart and dynamic DSF technologies in such climatic conditions.

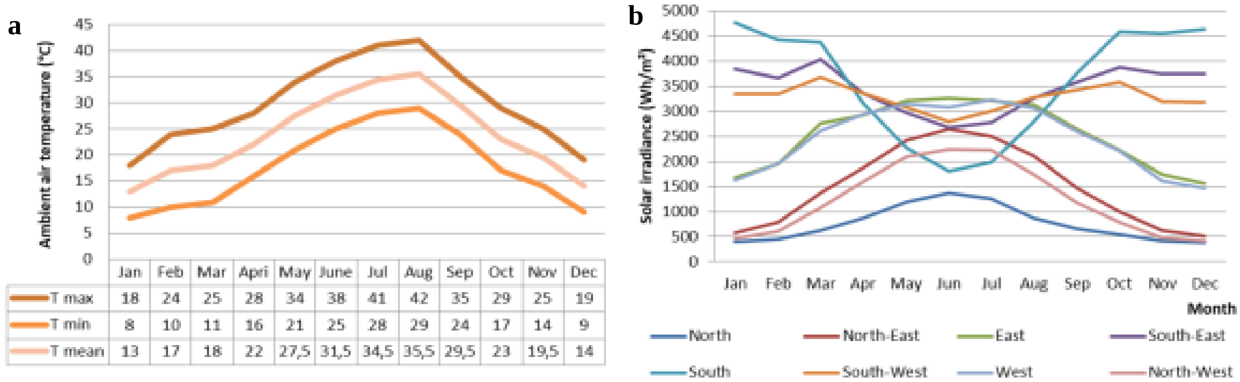
Climate conditions

The study case of this research was located in the Algerian desert exactly in the northeastern region, at 34.80°N latitude and 5.73°E longitude, with 82 meters of altitude above sea level. The Köppen–Geiger classification system identifies this zone as a hot, dry climate zone.

The International Weather for Energy Calculations database provides climatological data used for this study, in this case, the city of Biskra. The climate of Biskra is heavily impacted by sun radiation. Figure 4(b) summarizes monthly average sun irradiation levels for various exposures, illustrating the significant impact of solar radiation on the region's climatic conditions.

According to the temperature of the ambient air data for the city of Biskra presented in Figure 4(a), the hot season lasts from June until September. During this period, the mean maximum temperature is 35.5°C, and the minimum is 29.5°C. August is the warmest month, with an average high temperature of 42°C and a minimum of 29°C.

Conversely, the second half of November to the first week of March is a cooler season. During this period, the average maximum temperature is 19.5°C, with 13°C as the minimum temperature. January is considered the coldest month, with a mean maximum temperature of 18°C and 8°C as the minimum temperature.



	Jan	Feb	Mar	Apri	May	June	Jul	Aug	Sep	Oct	Nov	Dec
T max	18	24	25	28	34	38	41	42	35	29	25	19
T min	8	10	11	16	21	25	28	29	24	17	14	9
T mean	13	17	18	22	27,5	31,5	34,5	35,5	29,5	23	19,5	14

Fig. 4. a. *Temperature of the ambient air in (°C),* **b**. *Incident global irradiation on a vertical plane [44]*

Case study modeling

The building context in this research is a standard office building project situated in the city of Biskra. The building has two floors, with two office sections on each floor, separated by a corridor. Specifically, there are six offices on each floor, with the circulation area accounting for 15% of the total surface area [45].

The focus of the case study was on a south-oriented office within this building. The office has a window-to-wall ratio (WWR) of 10% and occupies 25 m² of the total area surface. Additionally, it is located on the ground floor, as illustrated in Figure 5.

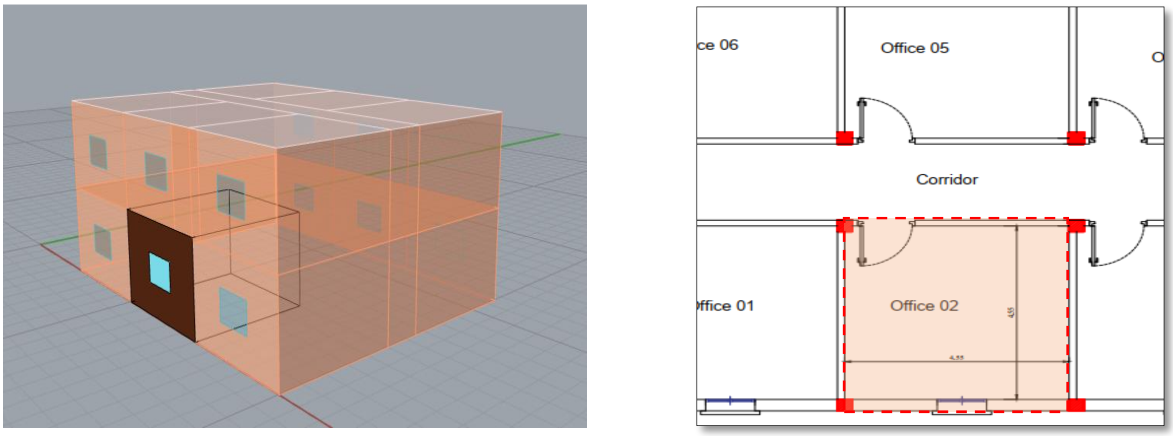


Fig. 5. *Case study 3D model and plan*

Materials

Table 1 shows the construction properties of the present model.

Table 1. Thermal properties of the building materials

	Thickness	U-Value W/(m^2·K)
Exterior wall	0.02 m of cement plaster	1.14
	0.15 m of hollow brick	
	0.05 m of air barrier	
	0.1 m of hollow brick	
	0.01 m of coated plaster	
Interior wall	0.01 m of coated plaster	2.49
	0.1 m of hollow brick	
	0.01 m of coated plaster	
Roof	0.02 m of flooring	2.42
	0.04 m of mortar	
	0.16 m of concrete blocks hollow	
	0.04 m of concrete slab	
	0.01 m of coated plaster	
Floor	0.15 m of clay	2.25
	0.15 m of stones of valley	
	0.04 m of concrete slab	
	0.04 m of mortar	
	0.02 m of flooring	

Windows material properties (Table 2)

Table 2. Thermal properties of the windows

Windows	Overall thickness (mm)	U-Value W/(m^2·K)	SHGC	Tvis
Single clear	3.05	5.84	0.74	0.60
Double low -E air	21.54	2.707	0.589	0.548
Double low -E vacuum	6.20	0.628	0.355	0.699
EC glazing	24.7	1.9	0.44(0.10)	0.64(0.01)

Modeling Tools

To comprehend the behavior of smart and dynamic facades in such specific buildings, energy analyses were developed using software based on parametric simulation. These tools offer the advantage of incorporating multiple plugins within the same platform. For instance, Grasshopper plays a pivotal role in parametric modeling, while software and simulation engines such as Ladybug and Honeybee serve as a comprehensive framework for visualization processes and energy and comfort simulation. Within this framework, Energy Plus and Open Studio handle energy simulations, while daylighting analysis is tasked by Radiance and Daysim.

After the parametric study, a genetic method - based on algorithms - is applied to improve solutions via the Galapagos plugin. Galapagos possesses the ability to perform multi-objective optimization, as depicted in Figure 6. This integrated approach enables a thorough examination of various design alternatives and facilitates the identification of optimal solutions for enhancing the energy efficiency of office buildings with smart and dynamic facades.

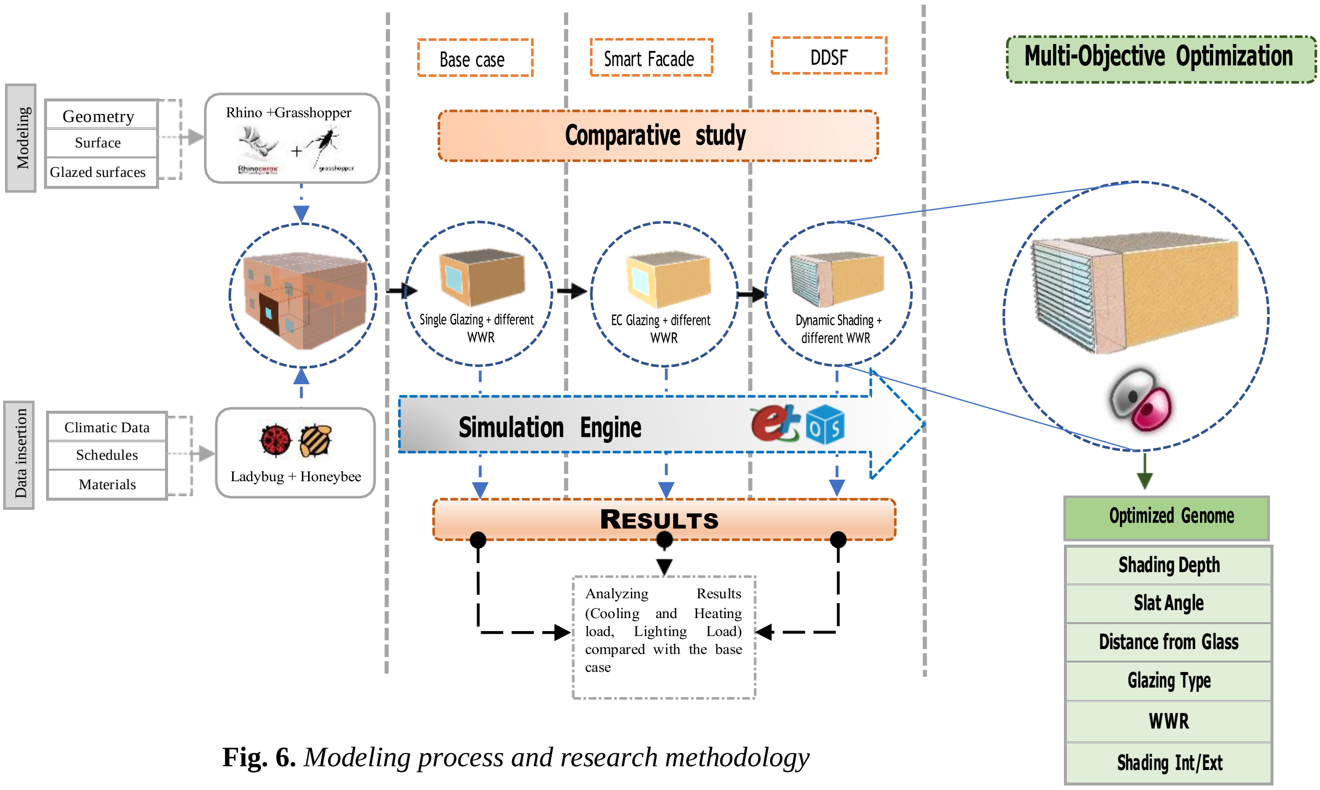


Fig. 6. *Modeling process and research methodology*

Methodology

The previous researches often focused on investigating electrochromic (EC) glazing, double-skin facades (DSF), or shading devices separately as the primary research focus. However, this work aims to analyze, compare, and optimize the combined effect of these technologies on energy consumption, particularly in hot and arid climates. The research methodology is divided into two main parts:

Comparison study

Simulation of base case and comparison with EC glazing and dynamic double-skin facade (DDSF)

- Simulation Setup:
  - Simulate a base case office building with simple glazing windows.
  - Vary the window-to-wall ratio (WWR) from 10% to 90%.
  - Use standard glazing properties for the base case.
- Energy Performance Evaluation:
  - Conduct energy simulations for each WWR scenario.

- Measure energy consumption for heating, cooling, and lighting.

- Comparison with EC Glazing:
  - Simulate the same office building scenarios but with EC Glazing.
  - Utilize properties listed in Table 2 for EC glazing.
  - Compare energy consumption with the base case.
- Dynamic double-skin facade (DDSF) simulation:
  - Model a dynamic double-skin facade with simple glazing on inner and outer skin.
  - Incorporate dynamic shading devices controlled by solar radiations incidents on the window and exterior air temperature.
  - Set the cavity depth to 100 cm.

Optimization

In the energy consumption optimization process, various parameters interact with each other, often presenting conflicting relationships. Galapagos, through its optimization algorithm, seeks to find a logical balance among these parameters. The optimization procedure is facilitated via the Galapagos plug-in, which requires two primary inputs to run effectively:

1. Fitness Parameter: This parameter serves as the basis for optimization, indicating whether the goal is to maximize or minimize certain criteria related to energy consumption.
2. Genomes: Six parameters are utilized within this component (referenced in Figure 6), each representing a specific property or aspect of the building design:
   - WWR south: ranges from 0.1 to 0.9, with increments of 0.3. to control the window-to-wall ratio (WWR) for the south-facing façade.
   - Window material: ranges from 0 to 2, with increments of 1, representing different window materials as detailed in Table 2.
   - Shading depth: ranges from 0 to 0.4, with increments of 0.1, which corresponds to shading depth.
   - Shading distance from glass: spans from 0 to 0.4, with increments of 0.3.
   - Shading angle: Ranges from 0 to 4, with increments of 1, corresponding to shading angles ranging from -0, 20, 45, 60, and 70 degrees, with increments of 1.
   - Shading position (interior/exterior): This parameter allows for the selection between interior and exterior shading positions.

Due to the unique environmental circumstances of the study case and the literature review results, the building conditions have been identified as follows:

Building characteristics	The base case description	Reference
Situation	Biskra, 34.80° N/ 5.73° A/82 m, Algeria	
Building orientation	180° (south)	
Plan form	Rectangular 4.55 m × 4.55 m	
Heating setpoint temperature	18°C	[46]
Cooling setpoint temperature	26°C	
Lighting setpoint for	300 lux	
Infiltration	0.0003 $m^3/(s \cdot m^2)$	[1]
Equipment charge	5 W/m²	
Lighting charge	5 W/m²	
Occupancy	0.2 ppl/mm²	
Weather file	Energy plus weather file	[2]
Shading control setpoint: High exterior air temperature	 26°C	[3], [47]
High solar radiation incidents on the window	500 W/m²	
Cavity depth	100 cm	[48]
COP	2.7	[49]

[1] ASHRAE Handbook, chapter 31: Energy Estimating and Modeling Methods; American Society of Heating, Refrigerating, and AirConditioning Engineers: Atlanta, GA, USA, 2001.
[2] EPW File. https://climate.onebuilding.or/WMO_Region_1_Africa /DZA_Algeria /index.html
[3] ISO13790, Energy performance of buildings, 2006.

Results and Discussion

The aim of this section is to evaluate the effectiveness of electrochromic (EC) glazing and dynamic double-skin façade (DDSF) systems in reducing energy consumption in office buildings located in hot, arid climates. The study was conducted by varying the window-to-wall ratio (WWR) and optimizing shading depth and angle to find the best-performing configurations.

Heating load of different façade systems according to different WWR (Figs.7,8)

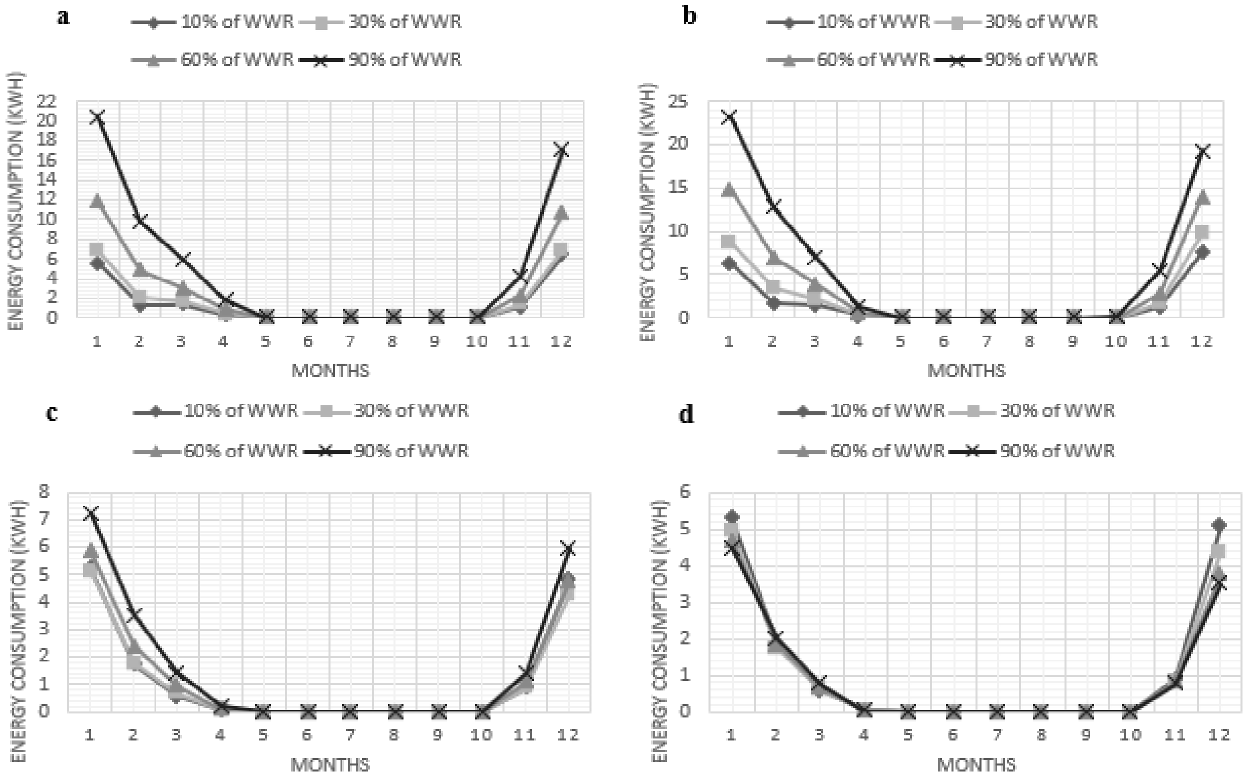


Fig. 7. *Heating energy consumption of different façade systems according to different WWR in kWh.* **a.** *simple glazing,* **b.** *EC glazing,* **c.** *DDSF 20 cm shading depth + 45° shading angle /INT: double low-E air /EXT: simple glazing,* **d.** *DDSF 20 cm shading depth + 45° shading angle /INT: double low-E vacuum/EXT: simple glazing*

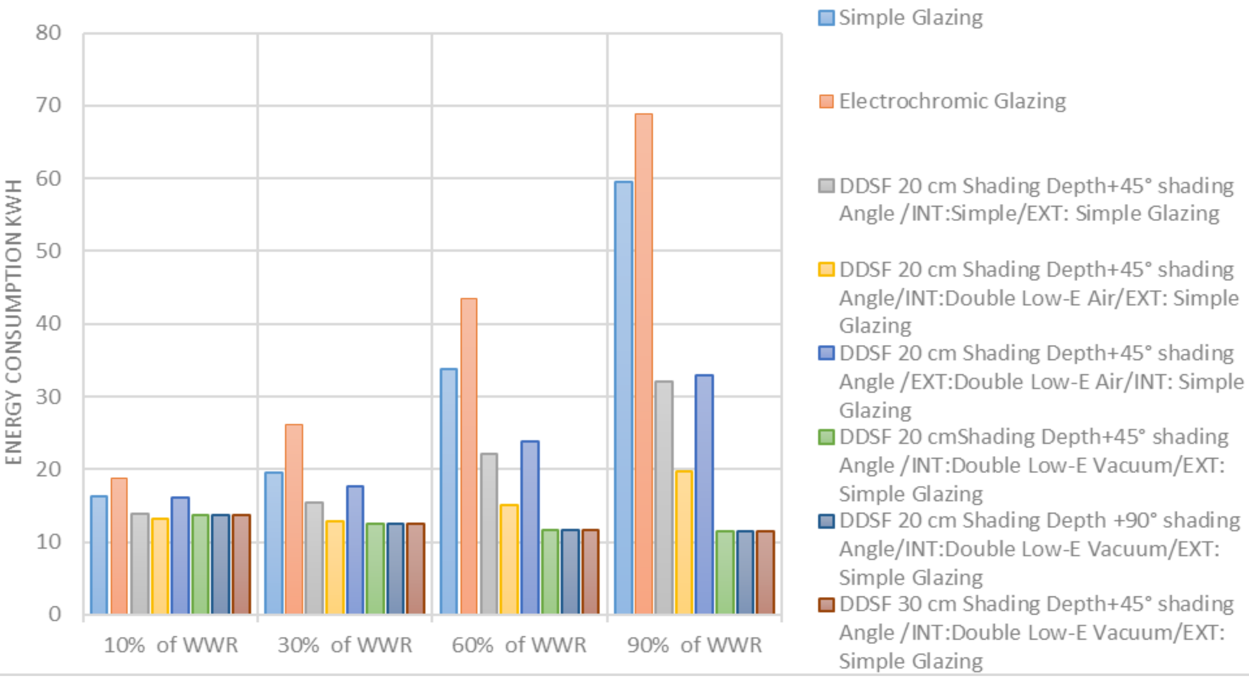


Fig. 8. *Energy heating loads of different façade systems according to different WWR in kWh*

Cooling load of different façade systems according to different WWR (Figs. 9,10)

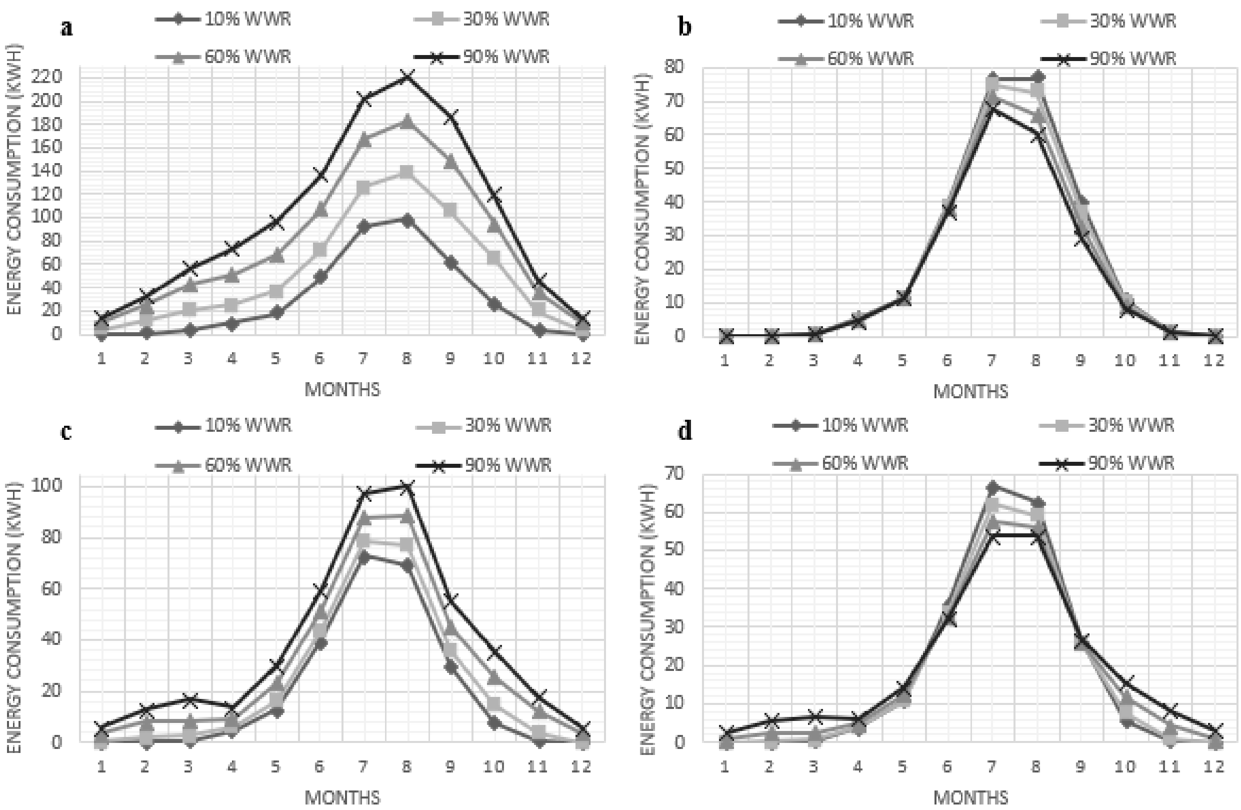


Fig. 9. *Cooling energy consumption of different façade systems according to different WWR in kWh.* **a.** *simple glazing*, **b.** *EC glazing*, **c.** *DDSF 20 cm shading depth + 45° shading angle/INT: double low-E air /EXT: simple glazing*, **d.** *DDSF 20 cm shading depth + 45° shading angle /INT: double low-E vacuum/EXT: simple glazing*

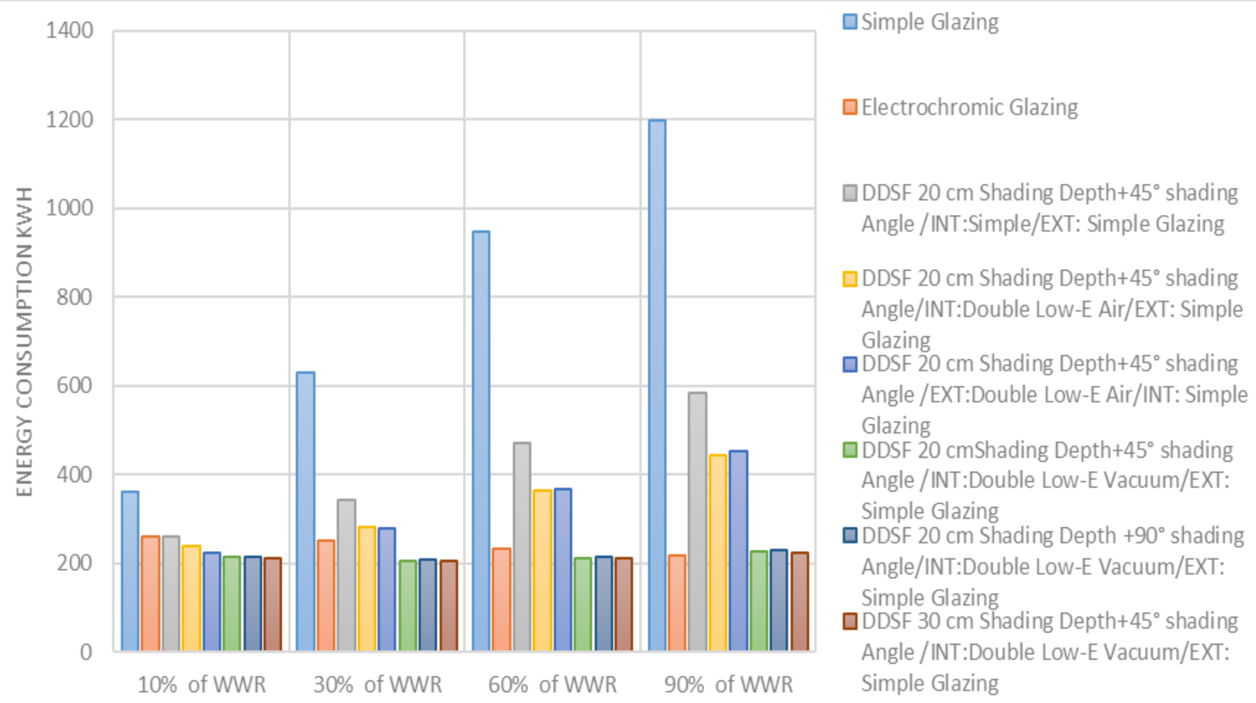


Fig. 10. *Energy cooling loads of different façade systems according to different WWR in kWh*

Lighting load of different façade systems according to different WWR (Figs.11,12)

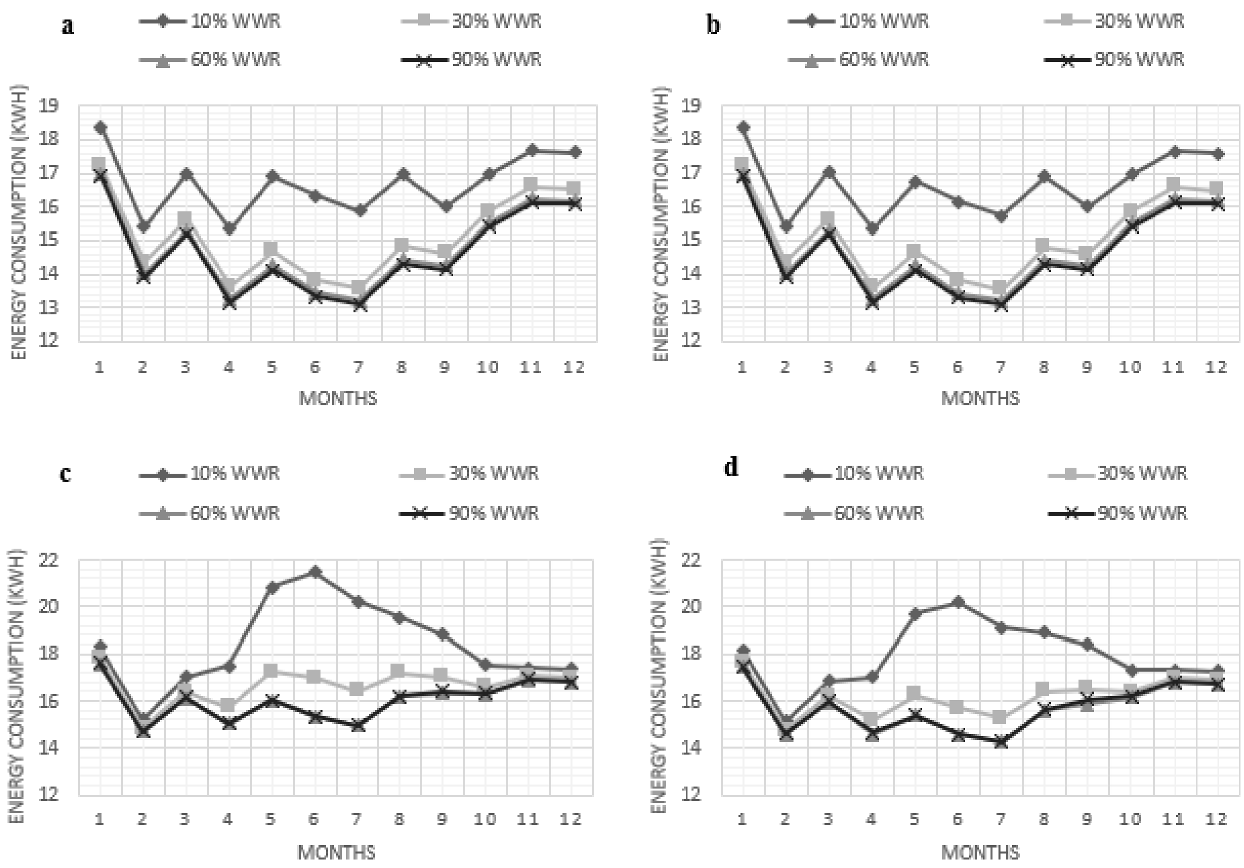


Fig. 11. *Lighting energy consumption of different façade systems according to different WWR in kWh.*
a. *simple glazing*, **b.** *EC glazing*, **c.** *DDSF 20 cm shading depth + 45° shading angle/INT: double low-E air /EXT: simple glazing*, **d.** *DDSF 20 cm shading depth + 45° shading angle /INT: double low-E vacuum/EXT: simple glazing*

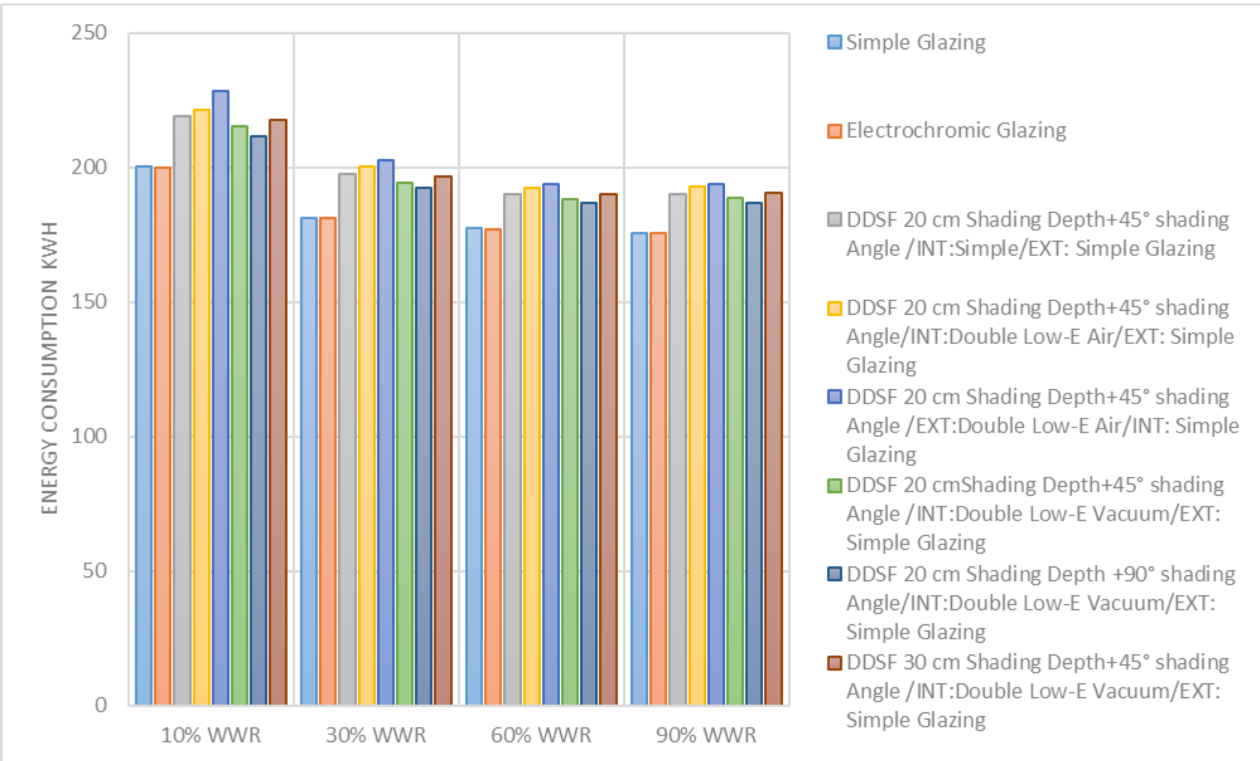


Fig. 12. *Lighting loads of different façade systems according to different WWR in kWh*

Overall energy consumption of different façade systems according to different WWR (Fig.13)

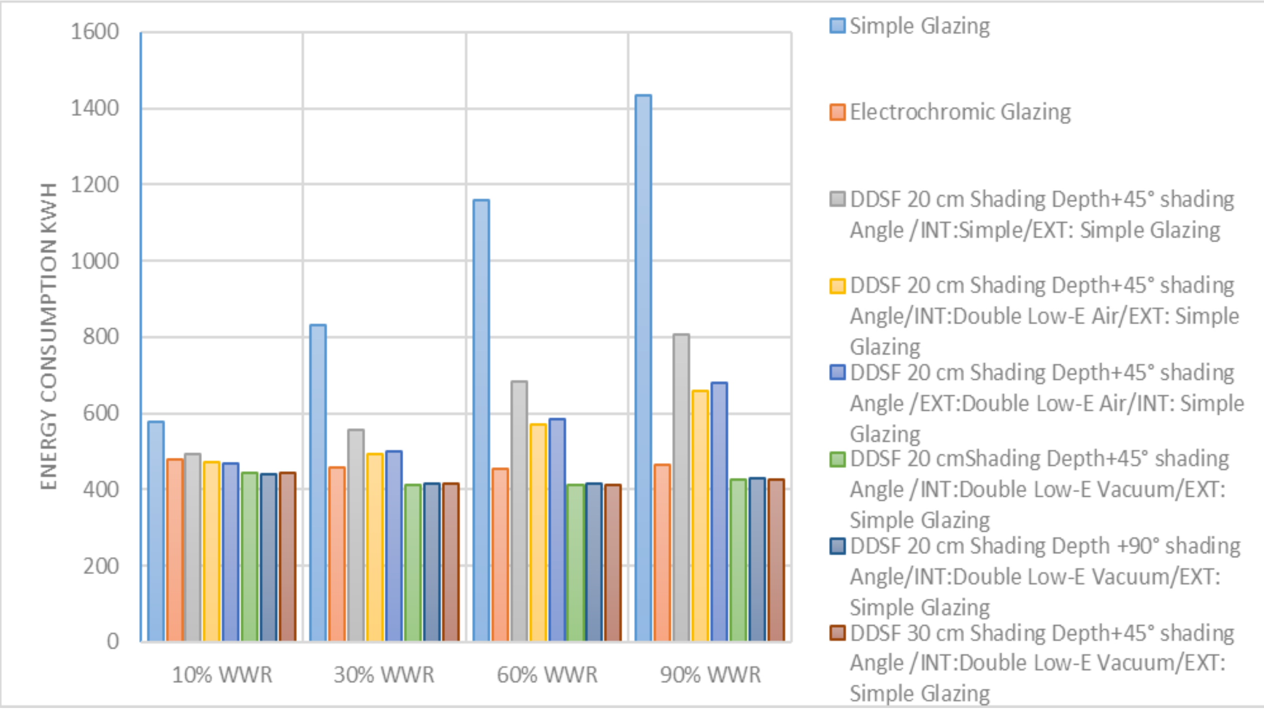


Fig. 13. *Overall energy consumption of different façade systems according to different WWR in kWh*

The results show that an increase in the window-to-wall ratio (WWR) correlates with higher energy consumption in the majority of the study cases, and this is because of the large amount of direct irradiation penetrating the building space. On the other hand, Figures 11 and 12 indicate that the decrease of energy consumption required for lighting is related to the increase of window-to-wall ratio WWR due to the important amount of sunlight entering the space.

Electrochromic (EC) Glazing

As shown in Figures 8,10,12, EC glazing consistently outperforms standard glazing across all WWR scenarios. For example, at a 90% WWR, the EC glazing reduces energy consumption for cooling by 67.65% compared to the base case (Table 3). This is primarily due to the EC glazing's ability to dynamically adjust its solar heat gain coefficient (SHGC) and visible light transmittance (Tvis), allowing it to block unwanted solar heat during the hot months while still providing natural daylight. In practical terms, this technology is particularly beneficial for large office buildings with expansive glass facades, as it can significantly reduce cooling loads during peak summer months in arid environments.

Dynamic double-skin façade (DDSF)

As demonstrated in Figures 8,10,12, when the DDSF system is optimized with a shading depth of 20 cm and an angle of 45°, it shows even more significant energy savings, particularly at higher WWR levels. For instance, at a 90% WWR, the DDSF system reduces overall energy consumption by 70.32% compared to the base case (Table 3). This is because the air cavity between the two layers of glazing acts as an insulating buffer, preventing heat transfer into the building while allowing for natural ventilation. The shading devices integrated into the DDSF system further reduce solar heat gain by blocking direct sunlight, especially during midday when solar radiation is highest.

The study demonstrates that the shading angle of 45° was optimal in blocking unwanted solar heat without obstructing too much daylight. Increasing the shading angle to 90° had a negligible effect on energy savings, suggesting that 45° provides the best balance between solar protection and natural lighting.

Comparison Between EC Glazing and DDSF

As indicated in Figure 13, while EC glazing offers significant energy savings, the DDSF system shows greater potential in climates with extreme solar exposure. The combination of dynamic shading and natural ventilation in the DDSF system not only reduces cooling loads but also improves thermal comfort within the building. However, EC glazing has the added advantage of better visual comfort, as it allows occupants to maintain a connection with the outside environment even when the windows are fully tinted.

These findings suggest that in hot, arid climates, the use of dynamic façade systems such as EC glazing and DDSF can drastically reduce the energy demand of office buildings, contributing to more sustainable architectural designs. The DDSF system, in particular, proves to be highly effective at large WWR levels, making it an ideal choice for modern office buildings where aesthetics and energy efficiency are both priorities.

Compared to previous researches, which showed energy savings up to 59% in [31], 48% in [36], and 34.3% in [39] with static double-skin facades, the optimized DDSF system in this study achieved up to 70.32% energy savings. This improvement can be attributed to the integration of advanced shading systems and the use of low-E vacuum glazing in the inner skin, which significantly reduced thermal transmission and improved overall building performance.

Overall, the study highlights the potential of EC glazing and DDSF systems in reducing energy consumption in arid climates, with DDSF offering the highest energy savings at higher WWR levels. These results underscore the importance of selecting the right façade system based on specific climatic conditions and building requirements.

Table 3. Overall energy saving compared to glazing reference in percentage **(%)**

Overall energy saving compared to glazing reference in percentage **(%)**				
	10% of WWR	30% of WWR	60% of WWR	90% of WWR
Simple glazing				
Electrochromic glazing	17.02	44.81	60.78	67.65
DDSF 20 cm shading depth + 45° shading angle / INT: simple / EXT: simple glazing	14.72	33.12	40.95	43.80
DDSF 20 cm shading depth + 45° shading angle / INT: double low-E air / EXT: simple glazing	18.17	40.51	50.68	54.17
DDSF 20 cm shading depth + 45° shading angle / EXT: double low-E air / INT: simple glazing	18.90	39.77	49.44	52.66
DDSF 20 cm shading depth +45° shading angle / INT: double low-E vacuum / EXT: simple glazing	23.50	50.33	64.54	70.32
DDSF 20 cm shading depth + 90° shading angle / INT: double low-E vacuum / EXT: simple glazing	23.90	50.19	64.31	70.10
DDSF 30 cm shading depth + 45° shading angle / INT: double low-E vacuum / EXT: simple glazing	23.20	50.13	64.44	70.25

In the previous results, the strategy variables were limited in some parameters, such as shading depth and shading angle. To understand more about the link between energy consumption and DDSF parameters and find the best configuration, a multi-objective optimization (MOO) via Galapagos is developed, and the results are shown in Figures 14,15.

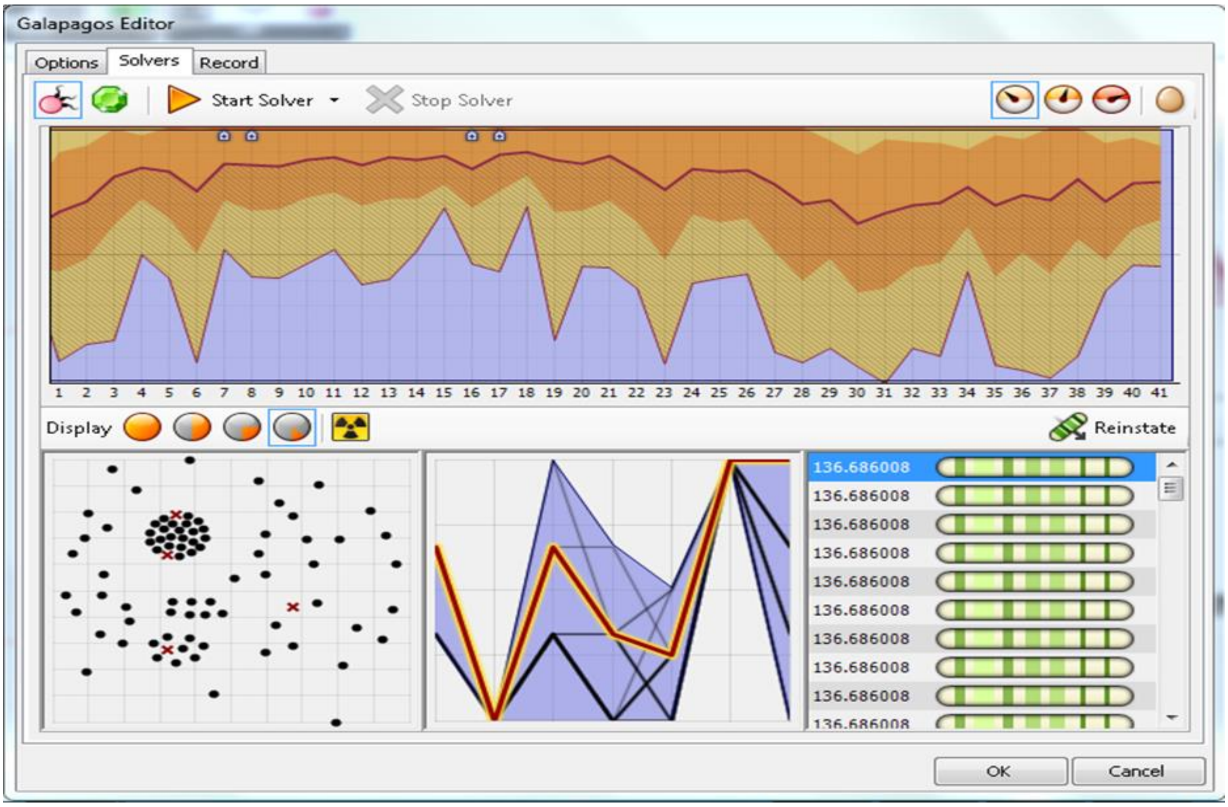


Fig. 14. *Multi-objective optimization process via Galapagos plugin*

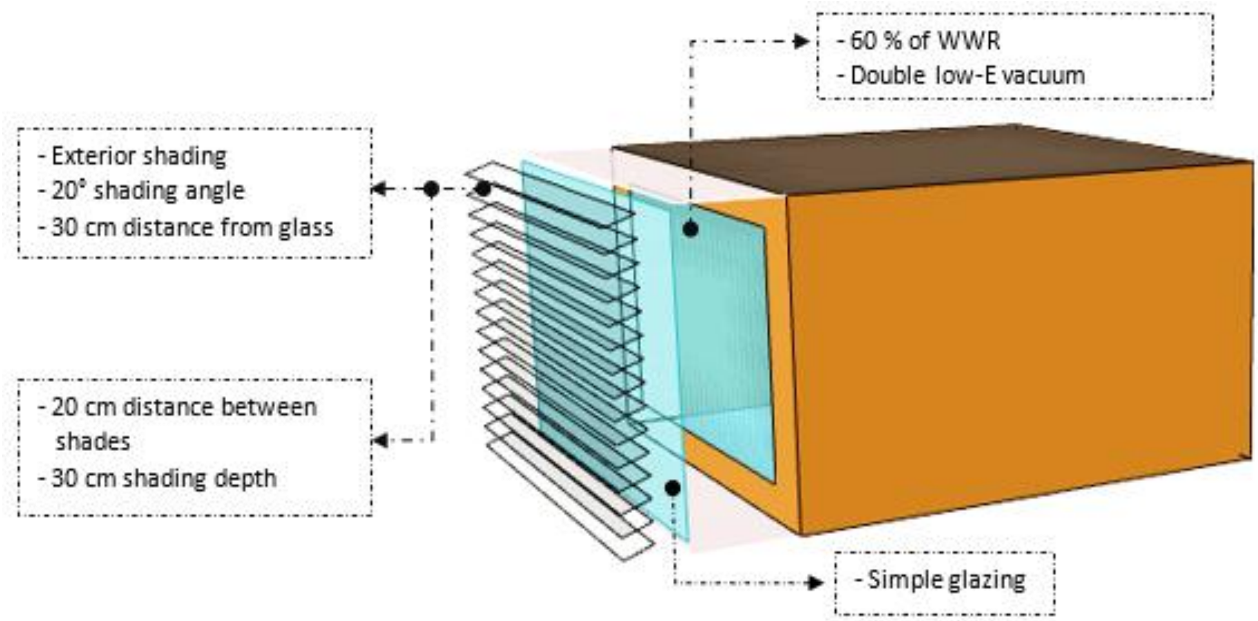


Fig. 15. *The best configuration of DDSF after multi-objective optimization*

Conclusion

The major goal of this research was to compare the feasibility of using a smart façade-electrochromic glazing system and dynamic ventilated double-skin façades (DDSFs) in office buildings in hot, arid region. Meanwhile, multi-objective optimization was developed to find the optimum configuration of DDSF in such climate conditions.

Consequently, it was found that the cooling energy load is more significant than the heating load due to the long summer period, which lasts almost seven months.

Moreover, the WWR has a considerable effect on energy consumption; an increase in the window-to-wall ratio (WWR) correlates with higher energy consumption used for heating, cooling, and lighting.

Meanwhile, it is preferred to use EC glazing in such climate conditions to reduce energy consumption. Using EC glazing as a smart active system is a good choice to reduce the direct radiation on the window. Thanks to its glazing properties such as visible light transmittance (Tvis) and solar heat gain coefficient (SHGC). The percentage between EC glazing and reference glazing in terms of saving energy in 90% of WWR is 67.65% which is a significant reduction.

This study demonstrates that smart and dynamic double-skin facades (DDSF), particularly when optimized for shading angle and depth, can result in substantial energy savings in hot, arid regions. The most efficient configuration tested reduced overall energy consumption by 70.32%, highlighting the potential for DDSF systems to play a critical role in sustainable architecture. These findings underscore the importance of integrating advanced facade technologies in regions with high solar exposure to optimize energy efficiency.

At this stage, this research is limited to the influence of DDSF on energy consumption while considering a few parameters such as shading depth, shading angle, etc. It will be more interesting for future researches to study other parameters such as cavity depth and color, shading materials, etc., and their effect on thermal and visual comfort.

Conflict of interest

The authors declare that they have no conflict of interest.

Financing

The study was performed without financial support.

Nomenclature

EC	electrochromic
DDSF	dynamic double-skin facade
WWR	window-to-wall ratio
Low E	low emissivity
WO3	tungsten trioxide
NiO	nickel oxide
U-values	thermal transmittance
SHGC	solar heat coefficient
Tvis	visible light transmittance
COP	coefficient of performance
MOO	multi-objective optimization

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PREDICTION OF SYNTHETIC SEISMOGRAMS AND ACCELEROGRAMS FOR TWO-LAYER BASIS BEDDINGS

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Abstract: *A method has been developed for predicting strong ground motion displacements and accelerations, assuming that an earthquake is an instantaneous mechanical rupture of the Earth's crust. The method uses derived theoretical formulas to calculate all three parameters of the ground motion: displacements, velocities, and accelerations during strong (with a magnitude of M≥6.0) earthquakes for any non-homogeneous (multilayer) ground beddings with various physical and mechanical characteristics – thicknesses, densities, and shear moduli – and at a certain distance from the expected earthquake's rupture. The example provided involves the results obtained for a number of two-layer heterogeneous site variants in seismic categories I-IV at the magnitude of M=7.0 and distance of 15 km from the expected earthquake's rupture. A comparison of the results obtained for actual heterogeneous foundation beddings with the equivalent homogeneous beddings showed divergences by 1.3-1.6 times, depending on the number of higher mode oscillations considered. Recommendations are provided for simplified calculation of seismograms and accelerograms for heterogeneous foundation beddings, with a certain correction of calculation results for equivalent homogeneous beddings.*

Keywords: *Prediction of synthetic seismograms and accelerograms, heterogeneous foundation (basis) bedding, seismic categories of soils.*

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Received: 01.07.2024
Revised: 28.09.2024
Accepted: 05.11.2024

Introduction

One of the main issues in seismic-resistant construction is the availability of a large number of accelerograms for past strong earthquakes at the site of a future construction project, recorded during a sufficiently long period. This would allow to identify statistically characteristic types of accelerograms for the given site and, therefore, to design reliable structures through calculations of seismic impact based on the selected accelerogram or a group of accelerograms. However, so far there have been too little records of past strong earthquakes in the seismically active zones of the Earth [1,2].

During an earthquake, in addition to the permanent (dead load weight) and imposed (weight of what is inside the building, rooftop snow, etc.) loads, buildings and structures are subjected to seismic loads. In reality, the latter are not loads (forces) per se. When the ground moves under a structure, due to inertia its individual parts move with a lag compared to the ground motion and the structure bends. This is similar to the impact of horizontal forces on the structure, which are perpendicular to its axis. These inertia forces are caused by the mass and rigidity of the superstructure. Values of these alternating inertia or seismic forces depend primarily on the alternating values of ground acceleration (accelerogram) during the earthquake. All of the above mentioned loads, except the seismic ones, create direct physical impact, have permanent direction, and exist during the whole useful lifespan of a structure. Seismic load has a dynamic nature and is active only during an earthquake. Therefore, seismic hazard parameters for a given area primarily depend on the values of horizontal (vertical, rotational) ground motion accelerations and their changes over the time [3]. This proves the importance of studying the issues related to creation of artificial seismograms and accelerograms for strong earthquakes that would adequately reflect the properties of actual recorded earthquakes. A brief overview of the problem was published in the initial articles [3,4]. The results of the studies published in the articles (in the opinion of many experts, close to the results recorded during real strong earthquakes) are apparently the only ones at the moment.

The choice of a two-layer base as an example of a heterogeneous base is due to the fact that for two-layer base the ratio V_{s1} and V_{s2} of the shear wave propagation velocities in soils during strong earthquakes plays a significant role in the magnitude of displacements and accelerations of the Earth's soil surface, and in many cases the cause of destruction of above-ground structures is the low value of the first layer velocity V_{s1}, (in some cases it is advisable to remove the "weak" first layer). In addition, any conventional multi-layer base can be reduced to a two-layer base with equivalent dynamic and seismic properties. Therefore, the main goal of this study is to cover all possible cases of different ratios V_{s1} and V_{s2} of two-layer bases (the article considers 16 cases). It should also be noted that in developing the forecasting method [3,4] the fundamental works of the following famous scientists were widely used: Brune J., Esteva L., Kasahara K., Wells D. and Coppersmith K., Lomnitz C. and Singh K., Faccioli E. and Resendiz D., etc [5-9].

Materials and Methods

In our previous works [3,4] a method was developed to predict strong ground motion displacements and accelerations, assuming that an earthquake is an instantaneous mechanical rupture of the Earth's crust (Fig.1.).

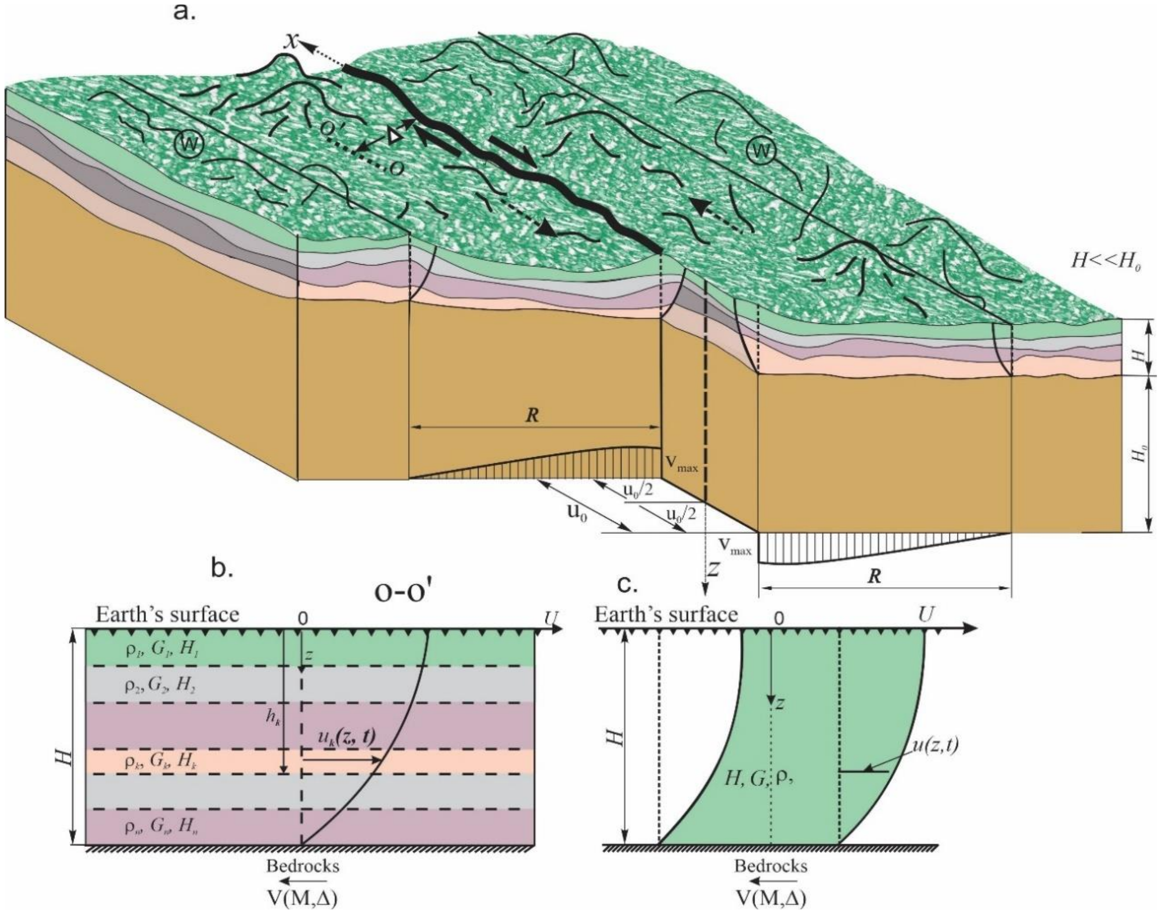


Fig. 1. *Schematic diagram of the medium after an earthquake-caused rupture:* ***a.*** *diagram of the rupture and the mechanical model of the upper strata,* ***b.*** *acceptable scheme of horizontal deformation of the vertical section along the O–O' line,* ***c.*** *the case of a homogenous near-surface thickness, H - total thickness of the surface layer, Δ - distance from the rupture line to the observation point, v_{max} - velocity of the blocks at the rupture, $v(M,\Delta)$ - velocity of the blocks at the distance Δ from the rupture, $u(z,t)$ - function of displacement in perpendicular direction relative to the rupture, ρ_k, G_k, H_k - density, shear modulus and thickness of the k-th layer, $H+H_0$ - depth of the rupture. Arrows indicate the block's movement direction after rupture, the heavy line shows the rupture direction, dotted arrows show the direction of the layers' inertia movements after rupture (medium compression and dilatation)*

The method uses derived theoretical formulas to calculate all three parameters of the ground motion: displacements, velocities and accelerations during strong (with a magnitude of $M \geq 6.0$) earthquakes for any non-homogeneous (multilayer) ground beddings with various physical and mechanical characteristics – thicknesses, densities and shear moduli and at certain distance of Δ from the expected earthquake's rupture.

For homogeneous (single-layer) foundation beddings, all typical parameters of the above-mentioned values and their changes over time (seismograms and accelerograms) for an earthquake with magnitude of $6.0 \leq M \leq 9.0$ were derived and found to be nearly identical to the same parameters of actual earthquakes. Earthquake response spectra derived from synthetic accelerograms were also quite similar to the response spectra obtained through actual earthquake accelerograms [10]. This study addresses making synthetic seismograms and accelerograms for two-layer heterogeneous foundation beddings.

For the general case, the functions of the foundation bedding layers' inertia movement $u_k(z,t)$ after an earthquake-caused rupture must match the following wave equations [4,11]:

$$G_k \frac{\partial^2 u_k}{\partial z^2} - \rho_k \frac{\partial^2 u_k}{\partial t^2} + \eta_k \frac{\partial^3 u_k}{\partial z^2 \partial t} = 0, \quad k = 1,2...n \tag{1}$$

where: G_k - the shear modulus of the k-th layer of the rocks, ρ_k - its density, η_k - the coefficient of viscosity, H_k - thickness of the k-th layer, n - the number of layers. The value of initial velocity for the inertial movement of layers (which is equal to the after-rupture plate velocity, but in the opposite direction) is assumed as per the following formula [4]:

$$v(M,\Delta) = 100 \cdot e^{M-8.5}\left(1 - \frac{\Delta^2}{R^2}\right), \tag{2}$$

which represents the initial velocity (in cm/sec) of soil particles' vibration at future rupture ($\Delta = 0$), or at a distance of Δ from it, where R is the length of the deformed area measured from the expected earthquake rupture (outside the area of R, the medium is assumed undeformed by the design earthquake). The values of the length R and average slip $\bar{u}$ (in meters) depending on the magnitude M are determined per the following formulas [10]:

$$R = (5\bar{u} + 15) \times 10^3, \quad \lg \bar{u} = 0.55M - 3.71. \tag{3}$$

The summary of the values for $v(M,\Delta)$, R and $\bar{u}$ are provided in Table 1, along with rock stratum ultimate (limit) shear strain values $\gamma_{\lim}$, which were determined by the new methodology developed in [10], according to which the relationship between $\gamma_{\lim}$ and earthquake magnitude M is as follows:

$$10^4 \gamma_{lim} = 0.39M - 2.23. \tag{4}$$

By assuming the solutions of the differential equation (1) as

$$u_k(z,t) = \sum_{i=1}^{\infty} U_{ki}(z) q_i(t), \quad h_{k-1} \le U_{ki}(z) \le h_k, \quad k = 1,2...n, \tag{5}$$

and satisfying the boundary and initial conditions of the problem [3], the following transcendental equation for multilayer system, free oscillations frequencies and values of functions $U_{ki}(z)$ and $q_i(t)$ are obtained. The final values of displacements (seismograms) and accelerations (accelerograms) at the ground surface (z=0) would be as follows [3]:

$$\begin{aligned} u_1(0,t) &= 100 \cdot e^{M-8.5}\left(1 - \frac{\Delta^2}{R^2}\right) \sum_{i=1}^{\infty} U_{1i}(0) \frac{T_{0i}}{2\pi} \delta_i e^{-\frac{\Theta}{T_{0i}}t} \sin\frac{2\pi}{T_{0i}} t \\ u_1''(0,t) &= 100 \cdot e^{M-8.5}\left(1 - \frac{\Delta^2}{R^2}\right) \sum_{i=1}^{\infty} U_{1i}(0) \frac{2\pi}{T_{0i}} \delta_i e^{-\frac{\Theta}{T_{0i}}t} \sin\frac{2\pi}{T_{0i}} t \end{aligned}, \tag{6}$$

$$\delta_i = \frac{\sum_{k=1}^{n} \int_{h_{k-1}}^{h_k} \rho_k U_{ki}(z) dz}{\sum_{k=1}^{n} \int_{h_{k-1}}^{h_k} \rho_k U_{ki}^2(z) dz}, \quad i = 1,2,3... . \tag{7}$$

where: $p_i = \frac{2\pi}{T_{0i}}$ - the angular frequency of the whole multilayer system's free oscillations derived from the relevant transcendental frequency equation, n_i - the foundation bedding's attenuation coefficient for the i-th mode ($n_i^2 << p_i^2$, $\boldsymbol{\eta_k = \eta = const, k = 1,2}$), T_{0i} - the period of the i-th mode of the foundation bedding particle's oscillation mode as shear seismic waves propagate with a velocity of (v_{Sk}) in the layers of a heterogeneous foundation bedding, and the functions $\boldsymbol{U_{ki}(z)}$ and $\boldsymbol{q_i(t)}$ are as follows:

$$\begin{aligned} &U_{ki}(z) = A_{ki} \sin \lambda_{ki} z + B_{ki} \cos \lambda_{ki} z \\ &q_i(t) = e^{-n_i t}\left(c_{1i} \sin p_i^* t + c_{2i} \cos p_i^* t\right), \; i = 1, 2,3... \\ &\frac{p_i^2 \rho_k}{G_k} = \lambda_{ki}^2, \; \frac{p_i^2 \eta}{G_k} = 2n_i, \quad p_i^* = \sqrt{p_i^2 - n_i^2} \approx p_i \end{aligned} . \tag{8}$$

Table 1. Values of the soil particles' oscillation velocities at the rupture $v(M,\Delta)$ in cm/sec, average slip $\overline{u}$ in meters, length of the deformed medium area R in km, and ultimate shear strain of ground γ_{lim} , depending on magnitude M and distance from the rupture Δ in km [10]

Magnitude M	**Average slip, $\overline{u}$ m**	**The length of deformed area measured from the rupture line, R, km**	**Rocks stratum ultimate (limit) shear strain values γ_{lim} x10^4 according to the formula (4)**	**Initial velocity at the rupture, v_{max}, cm/sec, ($\Delta = 0$)**	**Values of soil particles' oscillation velocities v (M,Δ) in cm/sec depending on magnitude M, and distance from the rupture ($\Delta < R$) in km[1]**																						
					Values of Δ, in km																						
					2	4	6	8	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
											17	24	27	32	39		48		59	61							101
											18																
											19																
6	0.39	16.9	0.11	8.2	8.1	7.7	7.2	6.4	5.3	1.7																	
6.25	0.54	17.7	0.21	10.5	10.4	10.0	9.3	8.4	7.2	3.0	0.8																
6.5	0.73	18.6	0.31	13.5	13.4	12.9	12.1	11.0	9.6	4.7	0.9																
6.75	1.00	20	0.40	17.4	17.2	16.7	15.8	14.6	13.0	7.6	1.7																
7	1.38	21.9	0.50	22.3	22.1	21.6	20.6	19.3	17.7	11.8	3.7																
7.25	1.90	24.3	0.60	28.7	28.5	27.9	26.9	25.5	23.8	17.7	9.2	0.7															
7.5	2.60	28	0.70	36.8	36.6	36.0	35.1	33.8	32.1	26.2	18.0	7.5	2.6														
7.75	3.57	32.8	0.79	47.2	47.1	46.5	45.7	44.4	42.8	37.4	29.7	19.8	7.7	2.3													
8	4.90	39.5	0.89	60.7	60.5	60.0	59.3	58.2	56.8	51.9	45.1	36.4	25.7	13.0	1.5												
8.25	6.73	48.6	0.99	77.9	77.7	77.4	76.7	75.8	74.6	70.5	64.7	57.3	48.2	37.5	25.1	11.1	1.9										
8.5	9.23	61.1	1.09	100.0	99.9	99.6	99.0	98.3	97.3	94.0	89.3	83.3	75.9	67.2	57.1	45.8	33.0	19.0	3.6	0.3							
8.75	12.68	78.4	1.18	128.4	128.3	128.1	127.7	127.1	126.3	123.7	120.0	115.3	109.6	102.8	95.0	86.1	76.2	65.2	53.2	40.1	26.0	10.9	1.3				
9	17.38	102	1.28	164.9	164.8	164.6	164.3	163.9	163.3	161.3	158.5	155.0	150.6	145.5	139.5	132.8	125.3	116.9	107.8	97.9	87.2	75.7	63.5	50.4	36.5	21.9	6.4 3.2

[1] The values of the oscillation velocities of soil particles $\boldsymbol{v}$ $(\boldsymbol{M},\Delta)$ for values $\Delta < \boldsymbol{R}$ that are not included in the main table are additionally indicated in green.

Eigenmodes of oscillations for a two-layer base

Creation of synthetic seismograms and accelerograms is addressed in detail below for a two-layer foundation bedding, the diagram of which is shown on Figure 2.

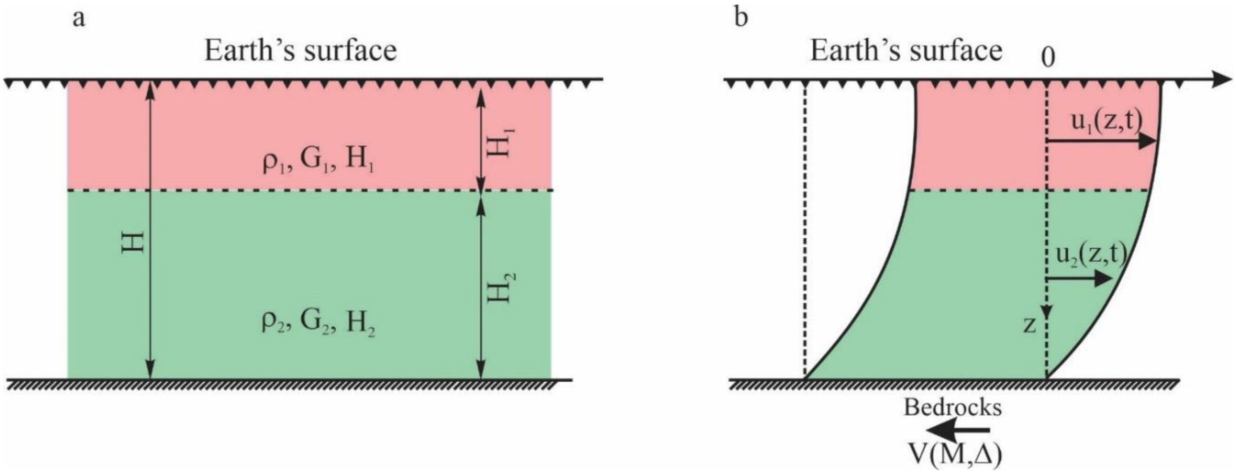


Fig. 2. *The diagram of a two-layer foundation bedding deformation*

The ground motion equation (1) for a two-layer foundation bedding is presented in the following forms:

$$G_1\frac{\partial^2 u_1}{\partial z^2}-\rho_1\frac{\partial^2 u_1}{\partial t^2}+\eta\frac{\partial^3 u_1}{\partial z^2\partial t}=0,\quad G_2\frac{\partial^2 u_2}{\partial z^2}-\rho_2\frac{\partial^2 u_2}{\partial t^2}+\eta\frac{\partial^3 u_2}{\partial z^2\partial t}=0\,. \tag{9}$$

Solutions of these equations by separation of variables can be presented as follows:

$$\begin{aligned} u_1(z,t) &= \sum_{i=1}^{\infty} U_{1i}(z)q_i(t) \quad \text{for} \quad 0\le z\le H_1 \\ u_2(z,t) &= \sum_{i=1}^{\infty} U_{2i}(z)q_i(t) \quad \text{for} \quad H_1\le z\le H_1+H_2 \end{aligned}\,. \tag{10}$$

Inserting (10) and (9) and separating variables for the functions U_{1i} and U_{2i}, as well as functions $q_i(t)$ the following equations are obtained:

$$\begin{aligned} &U_{1i}''(z)+\lambda_{1i}^2U_{1i}(z)=0,\ U_{2i}''(z)+\lambda_{2i}^2U_{2i}(z)=0,\ \lambda_{1i}^2=\frac{p_i^2\rho_1}{G_1},\ \lambda_{2i}^2=\frac{p_i^2\rho_2}{G_2} \\ &q_i''(t)+2n_iq_i'(t)+p_i^2q_i(t)=0,\ \frac{\eta p_i^2}{G_k}=2n_i,\quad (i=1,2,3...) \end{aligned}\,. \tag{11}$$

Solutions of the equations (11) are then presented in the following form:

$$\begin{aligned} &U_{1i}(z)=A_{1i}\sin\lambda_{1i}z+B_{1i}\cos\lambda_{1i}z, \\ &U_{2i}(z)=A_{2i}\sin\lambda_{2i}z+B_{2i}\cos\lambda_{2i}z \\ &q_i(t)=e^{-n_it}\left(c_{1i}\sin p_it+c_{2i}\sin p_it\right),\ i=1,2,3... \end{aligned}\,, \tag{12}$$

where n_i is the layers' attenuation coefficient for the i-th mode.

Satisfying the boundary conditions of medium continuity at the layer separation and the initial conditions which are as follows:

boundary and medium continuity condition:

$$\begin{aligned} &\text{for } z=0\quad G_1\frac{\partial u_1(z,t)}{\partial z}=0,\ \text{for } z=H_1+H_2\quad u_2(z,t)=0 \\ &\text{for } z=H_1\quad u_1(z,t)=u_2(z,t),\quad G_1\frac{\partial u_1(z,t)}{\partial z}=G_2\frac{\partial u_2(z,t)}{\partial z} \\ &\text{initial conditions:} \\ &\text{for } t=0\quad u_k(z,t)=0,\ k=1,2, \\ &\text{for } t=0\quad \frac{\partial u_k(z,t)}{\partial t}=v(M.\Delta),\ k=1,2 \end{aligned}\,. \tag{13}$$

From the first four homogeneous equations (13) with respect to A_{1i}, A_{2i}, B_{1i}, B_{2i} (from equality to zero of the 4th-order determinant) the following transcendental equation is derived for determining frequencies $p_i = \frac{2\pi}{T_{0i}}$ [4]:

$$\sqrt{\frac{\rho_1 G_1}{\rho_2 G_2}} tg \frac{2\pi H_1}{T_{0i}} \sqrt{\frac{\rho_1}{G_1}} \cdot tg \frac{2\pi H_2}{T_{0i}} \sqrt{\frac{\rho_2}{G_2}} - 1 = 0 . \quad (14)$$

The values of coefficients A_{1i}, A_{2i}, B_{1i}, B_{2i} have the following form:

$$\begin{aligned} &A_{1i} = 0 \\ &A_{2i} = -B_{1i} \frac{\cos \lambda_1 H_1}{\sin \lambda_2 H_2} \cos \lambda_2 (H_1 + H_2), \qquad U_{1i}(z) = B_{1i} \cos \frac{2\pi z}{T_{0i} v_{S1}} \\ &B_{2i} = B_{1i} \frac{\cos \lambda_1 H_1}{\sin \lambda_2 H_2} \sin \lambda_2 (H_1 + H_2), \qquad U_{2i}(z) = -B_{1i} \frac{\sin \lambda_1 H_1}{\cos \lambda_2 H_2} \sin \frac{2\pi (z - H)}{T_{0i} v_{S2}} \end{aligned} . \quad (15)$$

From the last two equations (13) for coefficients c_{1i}, and c_{2i} we obtain [4,7,8]:

$$c_{2i} = 0, \qquad c_{1i} = \frac{\mathrm{v}(M, \Delta) \left(\int_0^{H_1} \rho_1 U_{1i}(z) dz + \int_{H_1}^{H_1 + H_2} \rho_2 U_{2i}(z) dz \right)}{p_i \left(\int_0^{H_1} \rho_1 U_{1i}^2(z) dz + \int_{H_1}^{H_1 + H_2} \rho_2 U_{2i}^2(z) dz \right)}, \quad i = 1, 2, 3 \ldots \quad (16)$$

where $T_{0i} = 2\pi / \rho_i$ is the free oscillations period of the i-th mode for a two-layer foundation bedding, the values of which are determined by the transcendental equation (14).

The final expressions for displacements and accelerations at the ground surface (i.e. z=0 and assuming that the attenuation coefficient values n_i are small) will be:

$$\begin{aligned} u_1(0,t) &= 100 e^{M - 8.5} \left(1 - \frac{\Delta^2}{R^2} \right) \sum_{i=1}^{\infty} U_{1i}(0) \frac{T_{0i}}{2\pi} \delta_i e^{-\frac{\Theta_i}{T_{0i}} t} \sin \frac{2\pi}{T_{0i}} t \\ u_1''(0,t) &= 100 e^{M - 8.5} \left(1 - \frac{\Delta^2}{R^2} \right) \sum_{i=1}^{\infty} U_{1i}(0) \frac{2\pi}{T_{0i}} \delta_i e^{-\frac{\Theta_i}{T_{0i}} t} \sin \frac{2\pi}{T_{0i}} t \end{aligned} , \quad (17)$$

where δ_i and Θ are designated. Θ is the decrement of vibrations of rock particles, which is assumed to be the same for all oscillation modes of the base.

$$\delta_i = \frac{\rho_1 \int_0^{H_1} U_{1i}(z) dz + \rho_2 \int_{H_1}^{H_1 + H_2} U_{2i}(z) dz}{\rho_1 \int_0^{H_1} U_{1i}^2(z) dz + \rho_2 \int_{H_1}^{H_1 + H_2} U_{2i}^2(z) dz}, \quad i = 1, 2, 3 \ldots . \quad (18)$$

Inserting the values of $U_{1i}(z)$ and $U_{2i}(z)$ from (15) into (18), δ_i is derived as follows:

$$\delta_i = 4 \cdot \frac{\rho_1 \frac{v_{S1}}{v_{S2}} \sin \frac{2\pi H_1}{T_{0i} v_{S1}} + \rho_2 \frac{\cos \frac{2\pi H_1}{T_{0i} v_{S1}}}{\sin \frac{2\pi H_2}{T_{0i} v_{S2}}} \cdot \left(1 - \cos \frac{2\pi H_2}{T_{0i} v_{S2}} \right)}{B_{1i} \left[\rho_1 \frac{v_{S1}}{v_{S2}} \left(\frac{4\pi H_1}{T_{0i} v_{S1}} + \sin \frac{4\pi H_1}{T_{0i} v_{S1}} \right) + \rho_2 \left(\frac{\cos \frac{2\pi H_1}{T_{0i} v_{S1}}}{\sin \frac{2\pi H_2}{T_{0i} v_{S2}}} \right)^2 \left(\frac{4\pi H_2}{T_{0i} v_{S2}} - \sin \frac{4\pi H_2}{T_{0i} v_{S2}} \right) \right]}, \quad i = 1, 2, 3 \ldots . \quad (19)$$

Values of the constant B_{1i} can be assumed to be equal to 1 ($B_{1i} = 1$), because considering formulas (15) and (19), the final forms of (17) for seismograms and accelerograms $u_1(0,t)$ and $u_1''(0,t)$, the values of B_{1i} will cancel out.

Accelerograms of two-layer and their equivalent single-layer foundations on the Earth's surface

The 16 variants of heterogeneous foundation beddings are considered: the main parameters are presented in Table 2 and Figure 3, where H_1 and H_2, v_{S1} and v_{S2}, ρ_1 and ρ_2 are thicknesses, propagation velocities of seismic shear waves and ground layer densities, respectively, while free oscillation periods T_{01}, T_{02} and T_{03} for all 16 heterogeneous beddings are derived from the transcendental equations of frequencies (14), and values of coefficients δ_i are obtained from the formula (19).

Table 2. Physical and mechanical properties of heterogeneous foundation beddings

Heterogeneous foundation beddings												
№	V_{s1}, cm/s	H_1, m	ρ_1, t*s^2/m^4	V_{s2}, cm/s	H_2, m	ρ_2, t*s^2/m^4	**Derived from the formula (14)**			**According to the formula (19)**		
							T_{01}, s	T_{02}, s	T_{03}, s	δ_1	δ_2	δ_3
1.	400	10	0.2	600	20	0.22	0.207	0.073	0.047	1.891	-0.522	0.483
2.	250	10	0.2	600	20	0.22	0.232	0.107	0.056	1.865	-0.873	0.861
3.	200	10	0.2	400	20	0.22	0.380	0.151	0.080	1.723	-0.701	0.714
4.	150	10	0.2	300	20	0.2	0.458	0.190	0.100	1.842	-0.787	0.498
5.	150	15	0.2	250	15	0.22	0.657	0.191	0.127	2.095	-1.000	0.704
6.	125	15	0.2	200	15	0.2	0.925	0.308	0.154	1.903	-0.488	0.486
7.	100	5	0.18	600	25	0.22	0.246	0.145	0.069	1.256	-1.104	0.867
8.	600	25	0.22	100	5	0.18	0.740	0.107	0.079	6.329	-0.126	0.330
9.	530	13	0.22	600	17	0.22	0.203	0.071	0.042	2.250	-0.612	0.465
10.	620	14	0.22	700	16	0.22	0.174	0.061	0.036	2.406	-0.631	0.510
11.	340	18	0.2	400	12	0.2	0.245	0.098	0.063	3.491	-1.105	0.346
12.	450	14	0.22	550	16	0.22	0.336	0.074	0.054	1.789	-0.672	0.346
13.	280	16.5	0.2	350	13.5	0.22	0.365	0.132	0.078	2.729	-0.813	0.688
14.	150	15	0.2	200	15	0.22	0.667	0.222	0.138	2.442	-0.816	0.623
15.	208	20	0.2	150	12	0.2	0.785	0.228	0.143	3.282	-0.587	0.443
16.	200	4.8	0.1626	300	30.7	0.1775	0.469	0.160	0.100	1.241	-0.604	0.437

Equivalent homogeneous beddings													
№	V_{s1}, cm/s	H_1, m	ρ_1, t*s^2/m^4	V_{s2}, cm/s	H_2, m	ρ_2, t*s^2/m^4	$\bar{V}_s$, cm/s	$\bar{T}_{01}$, s	$\bar{T}_{02}$, s	$\bar{T}_{03}$, s	$\bar{\delta}_1$	$\bar{\delta}_2$	$\bar{\delta}_3$
1.	400	10	0.2	600	20	0.22	514	0.233	0.078	0.047	1.274	-0.425	0.255
2.	250	10	0.2	600	20	0.22	409	0.293	0.098	0.059	1.274	-0.425	0.255
3.	200	10	0.2	400	20	0.22	300	0.400	0.133	0.080	1.274	-0.425	0.255
4.	150	10	0.2	300	20	0.2	225	0.533	0.178	0.107	1.274	-0.425	0.255
5.	150	15	0.2	250	15	0.22	187	0.640	0.213	0.128	1.274	-0.425	0.255
6.	125	15	0.2	200	15	0.2	153	0.780	0.260	0.156	1.274	-0.425	0.255
7.	100	5	0.18	600	25	0.22	327	0.367	0.122	0.073	1.274	-0.425	0.255
8.	600	25	0.22	100	5	0.18	327	0.367	0.122	0.073	1.274	-0.425	0.255
9.	530	13	0.22	600	17	0.22	567	0.211	0.070	0.042	1.274	-0.425	0.255
10.	620	14	0.22	700	16	0.22	660	0.182	0.061	0.036	1.274	-0.425	0.255
11.	340	18	0.2	400	12	0.2	361	0.332	0.111	0.066	1.274	-0.425	0.255
12.	450	14	0.22	550	16	0.22	498	0.241	0.080	0.048	1.274	-0.425	0.255
13.	280	16.5	0.2	350	13.5	0.22	307	0.390	0.130	0.078	1.274	-0.425	0.255
14.	150	15	0.2	200	15	0.22	171	0.700	0.233	0.140	1.274	-0.425	0.255
15.	208	20	0.2	150	12	0.2	181	0.705	0.235	0.141	1.274	-0.425	0.255
16.	200	4.8	0.1626	300	30.7	0.1775	281	0.505	0.168	0.101	1.274	-0.425	0.255

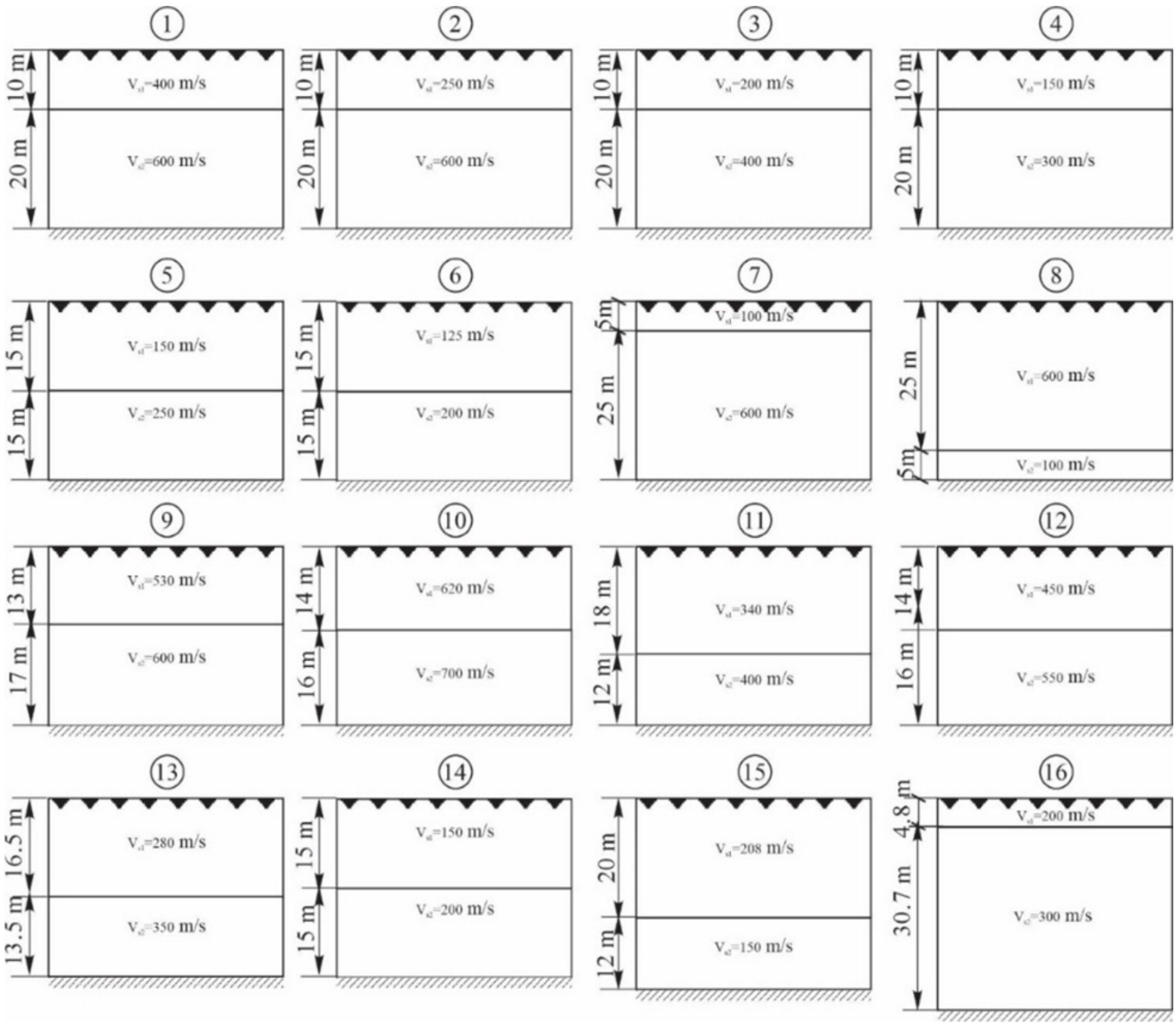


Fig. 3. *Diagrams of the considered heterogeneous foundation beddings*

Table 2 also provides the physical and mechanical characteristics for all equivalent homogeneous foundation beddings: average values of propagation velocity of displacement waves $\bar{v}_S$ and densities $\bar{\rho}$, which are determined by the following formulas[2].

$$\bar{v}_S = \frac{H_1 + H_2}{\dfrac{H_1}{v_{s1}} + \dfrac{H_2}{v_{s2}}}, \quad \bar{\rho} = \frac{H_1\rho_1 + H_2\rho_2}{H_1 + H_2}. \tag{20}$$

Values of the equivalent homogeneous foundation bedding first period are determined by the following formula:

$$\bar{T}_0 = 4(H_1 + H_2)/\bar{v}_s, \tag{21}$$

whereas values of the next periods $\bar{T}_{0i}$ (i=2,3,4…) and coefficients $\bar{\delta}_i$ (i=1,2,3…) are assumed by the formulas for a homogeneous foundation bedding [4,10]:

$$\bar{T}_{0i} = \frac{\bar{T}_{01}}{2i-1}, \ (i=2,3,4\ldots), \quad \bar{\delta}_i = \frac{4}{\pi} \cdot \frac{(-1)^{i+1}}{2i-1}, \qquad i=1,2,3\ldots . \tag{22}$$

[2] RABC 20.04-2020. Earthquake Resistant Construction. Design Codes. Yerevan, 2020.

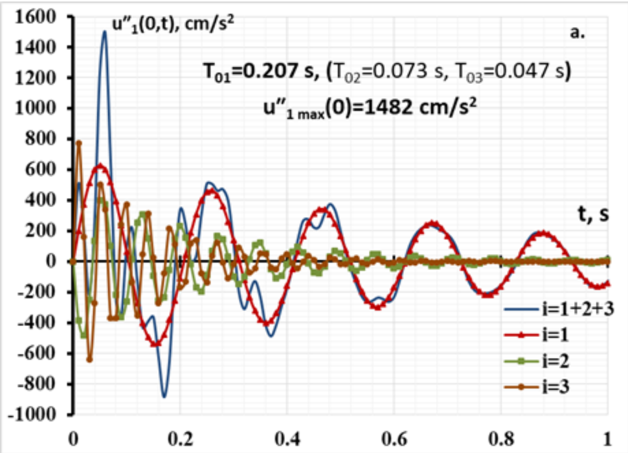
The final results of calculations according to formulas (17) for peak ground displacements and accelerations under M=7.0, Δ=15 km, and ground vibration decrement $\Theta_i = n_i T_{0i} = const\ (i = 1,2,3 \dots) = 0.3$ are provided in Table 3. As seen in the Table, when replacing heterogeneous bedding with an equivalent homogeneous one, the best approximation for ground accelerations u''_{0max} and $\overline{u}''_{0max}$ occurs when the accelerograms of the equivalent heterogeneous bedding are calculated factoring in five modes of oscillation, while for the heterogeneous bedding it is done in three modes.

Table 3. Peak values of seismograms and accelerograms for 16 heterogeneous beddings and equivalent homogeneous beddings

№	Heterogeneous beddings			Equivalent homogeneous bedding					Ratios of real displacements and accelerations of heterogeneous stratification taking into account **three** modes of oscillations to the **equivalent** taking into account **five** modes of oscillations	
	First oscillation mode period T_{01}, sec	Actual values of displacements and accelerations with consideration of **three** oscillations modes according to the formula (17)		Average values of the first oscillation mode period $\overline{T}_{01}$, sec	Equivalent values of displacements and accelerations with consideration of **three** oscillations modes according to the formula (17)		Equivalent values of displacements and accelerations with consideration of **five** oscillations modes according to the formula (17)			
		$u_{1max}(0)$, cm	$u''_{1max}(0)$, cm/s^2		$\overline{u}_{1max}(0)$, sm	$\overline{u}''_{1max}(0)$, sm/s^2	$\overline{u}_{1max}(0)$, sm	$\overline{u}''_{1max}(0)$, sm/s^2	$\frac{u_{1max}(0)}{\overline{u}_{1max}(0)}$	$\frac{u''_{1max}(0)}{\overline{u}''_{1max}(0)}$
1	0.207	0.75	1482	0.233	0.58	965	0.591	1374	1.29	1.08
2	0.232	0.88	1714	0.293	0.73	768	0.745	1077	1.21	1.59
3	0.380	1.35	1008	0.400	1.00	572	1.021	833	1.35	1.21
4	0.458	1.70	737	0.533	1.34	428	1.361	617	1.27	1.19
5	0.657	2.79	782	0.640	1.61	357	1.634	520	1.73	1.50
6	0.925	3.35	370	0.780	1.96	292	1.991	421	1.71	0.88
7	0.246	0.63	1173	0.367	0.92	623	0.937	901	0.68	1.30
8	0.740	8.24	794	0.367	0.92	623	0.937	901	8.96	0.88
9	0.203	0.89	1799	0.211	0.53	1057	0.535	1460	1.68	1.23
10	0.174	0.80	1959	0.182	0.44	1085	0.444	1266	1.82	1.55
11	0.245	1.62	1796	0.332	0.83	682	0.846	970	1.95	1.85
12	0.336	1.08	1049	0.241	0.60	950	0.615	1383	1.80	0.76
13	0.365	1.95	1309	0.390	0.97	579	0.990	829	2.01	1.58
14	0.667	3.23	699	0.700	1.76	325	1.786	467	1.84	1.50
15	0.785	4.77	592	0.705	1.77	321	1.797	462	2.69	1.28
16	0.469	1.09	622	0.505	1.26	445	1.283	635	0.87	0.98
Average value excludes № 7 and 8[3]									1.66	1.3

Figure 4 shows superposition of the first three oscillation modes for heterogeneous (a) and equivalent homogeneous (b) foundation beddings. As it is apparent, although for the individual oscillation modes peak occurrences hardly differ in time, the resulting acceleration for the heterogeneous bedding on average is higher by 1.3 times compared to accelerations of the homogeneous bedding. Therefore, unlike with homogeneous bedding, the superposition process in heterogeneous one largely depends on coefficients δ_i, the values of which, unlike periods T_{0i}, depend on the medium deformation dynamic mode functions $U_{ki}(z)$ (k=1, 2). This is obvious also in Table 4, which provides comparative characteristics of the first oscillation modes for heterogeneous and equivalent homogeneous foundation beddings.

[3] These variants are excluded because the physical and mechanical properties of their layers significantly differ from each other, and therefore, the "method of averaging" is not applicable to them.



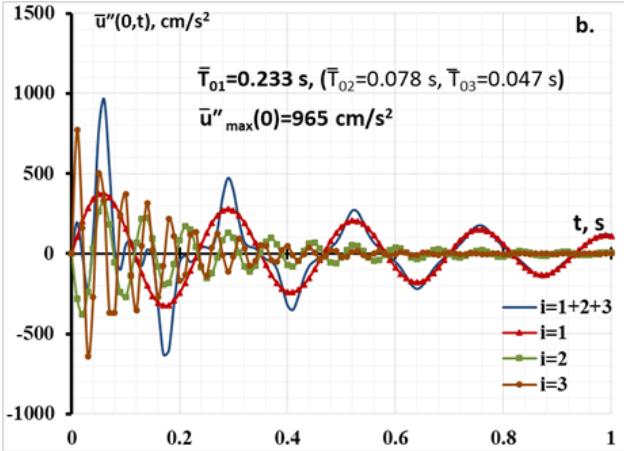


Fig. 4. *Acceleration time history curves (at ground surface) according to the formula (17): for individual oscillation modes (first i=1, second i=2, and third i=3), and their sum (i=1+2+3), for the № 1 variant of heterogeneous foundation bedding with* $T_{01} = 0.207$ *sec (a) and for the equivalent homogeneous bedding with average value* $\overline{T}_{01} = 0.233$ c. *(b), under: M=7.0, Δ=15 km,* $\Theta_1=\Theta_2=\Theta_3=0.3$

Table 4. Comparative characteristics of the fundamental oscillation periods and modes for heterogeneous and equivalent homogeneous foundation beddings

№	T_{01}, s	$\overline{T}_{01}$, s	$\frac{\overline{T}_{01}}{T_{01}}$	δ_1	δ_2	δ_3	$\frac{\delta_1}{\delta_2}$	$\frac{\delta_1}{\delta_3}$	$\overline{\delta}_1$ [4]	$\frac{\delta_1}{\overline{\delta}_1}$
1	0.207	0.233	1.127	1.890	-0.522	0.483	3.62	3.92	1.274	1.483
2	0.232	0.293	1.266	1.865	-0.873	0.861	2.14	2.17	1.274	1.464
3	0.380	0.400	1.053	1.723	-0.701	0.714	2.46	2.41	1.274	1.352
4	0.458	0.533	1.164	1.842	-0.787	0.498	2.34	3.70	1.274	1.446
5	0.657	0.640	0.974	2.095	-1.000	0.704	2.10	2.98	1.274	1.645
6	0.925	0.780	0.843	1.903	-0.488	0.486	3.90	3.91	1.274	1.494
7	0.246	0.367	1.492	1.256	-1.104	0.867	1.14	1.45	1.274	0.986
8	0.740	0.367	0.495	6.329	-0.126	0.330	50.07	19.15	1.274	4.968
9	0.203	0.211	1.042	2.250	-0.612	0.465	3.67	4.84	1.274	1.766
10	0.174	0.182	1.044	2.406	-0.631	0.510	3.81	4.72	1.274	1.889
11	0.245	0.332	1.354	3.491	-1.105	0.346	3.16	10.09	1.274	2.740
12	0.336	0.241	0.718	1.789	-0.672	0.346	2.66	5.17	1.274	1.404
13	0.365	0.390	1.069	2.729	-0.813	0.688	3.36	3.96	1.274	2.142
14	0.667	0.700	1.050	2.442	-0.816	0.623	2.99	3.92	1.274	1.917
15	0.785	0.705	0.898	3.282	-0.587	0.443	5.59	7.41	1.274	2.576
16	0.469	0.505	1.076	1.241	-0.604	0.437	2.05	2.84	1.274	0.974
Average value excludes № 7 and 8			1.05				3.1	4.4		1.73

Seismograms and accelerograms for the first 8 variants are shown in Figure 5.

[4] The ratio $\overline{\delta}_1/\overline{\delta}_i$ for any homogeneous bedding equals to $(-1)^{i+1}(2i-1)$, (i=1,2,3…).

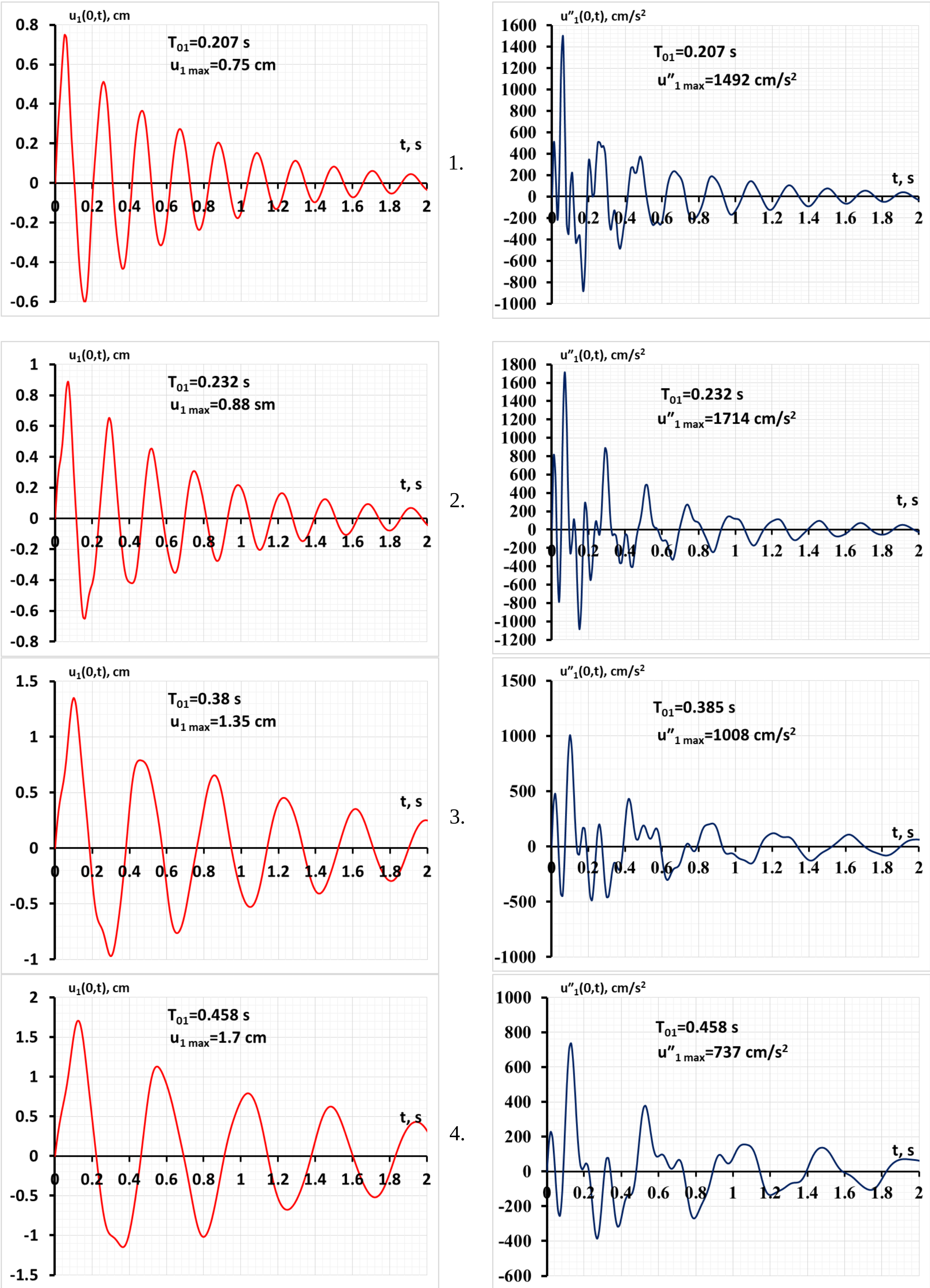
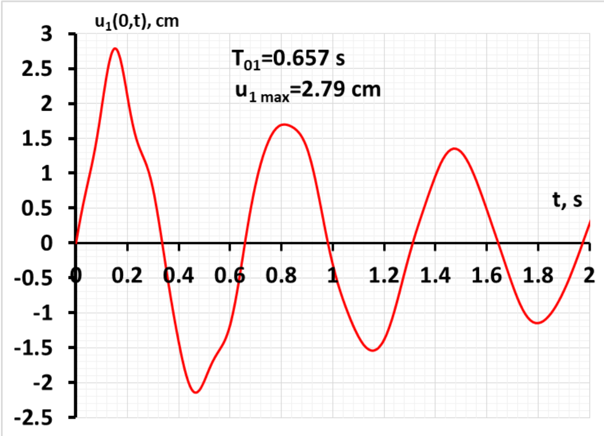
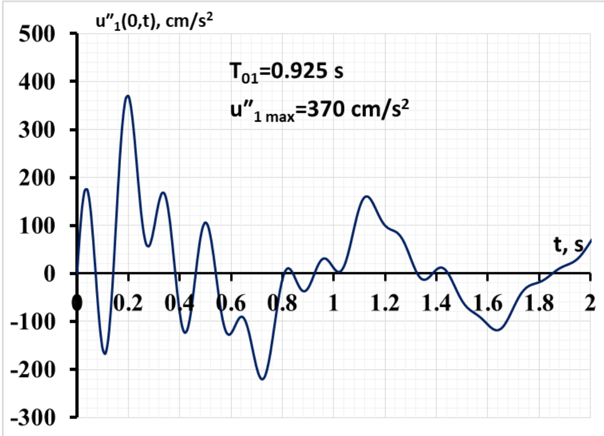


Fig. 5. *Synthetic seismograms and accelerograms of 16 variants of heterogeneous foundation beddings (Fig.3)*

Fig. 5. (continued)





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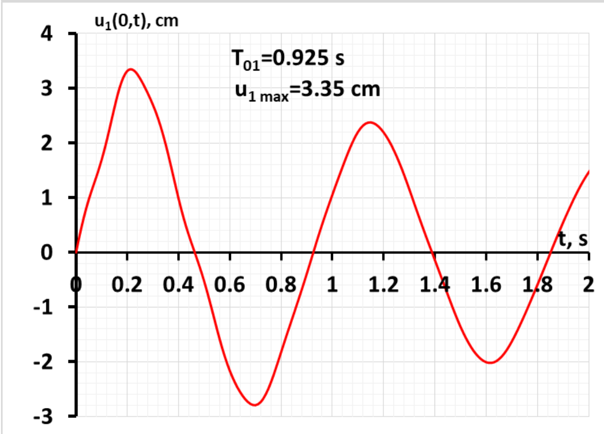

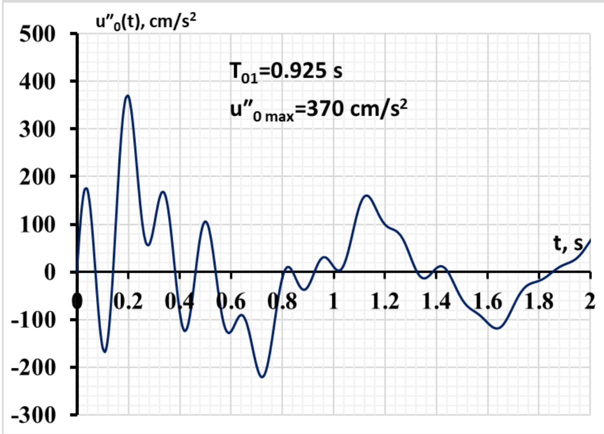

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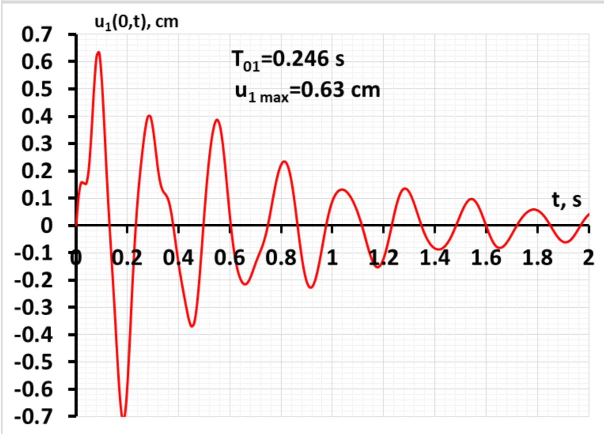

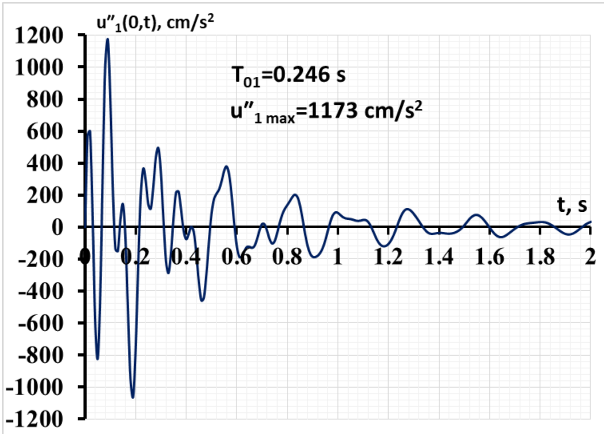

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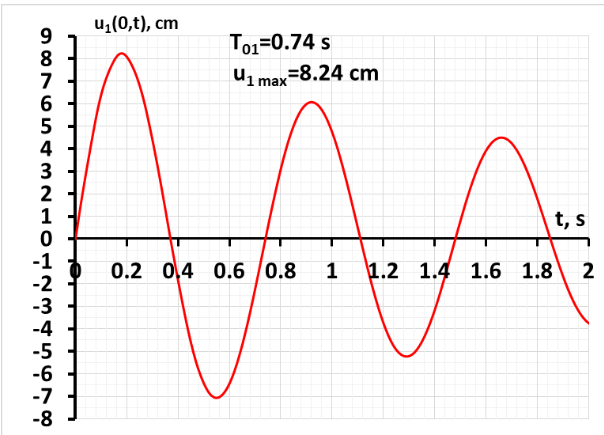

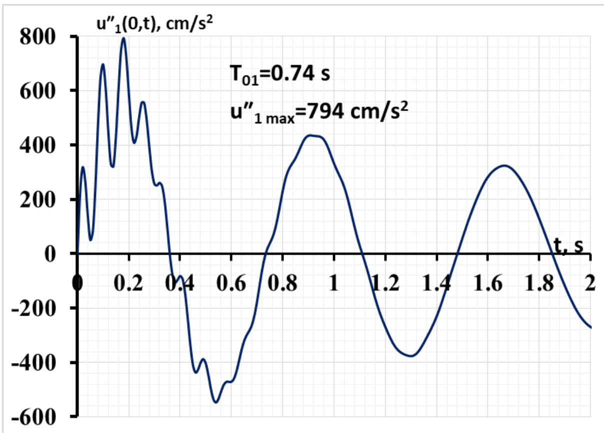

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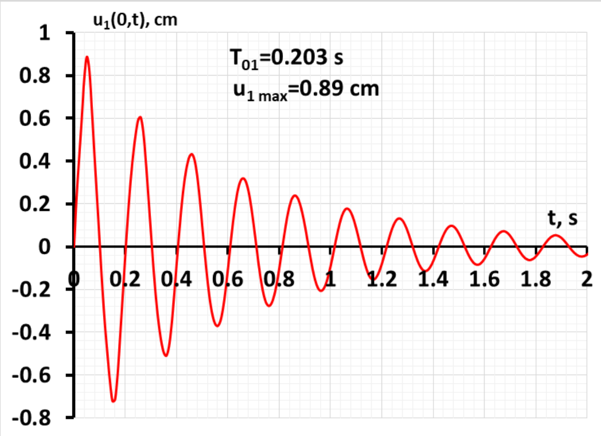
Fig. 5. (continued)



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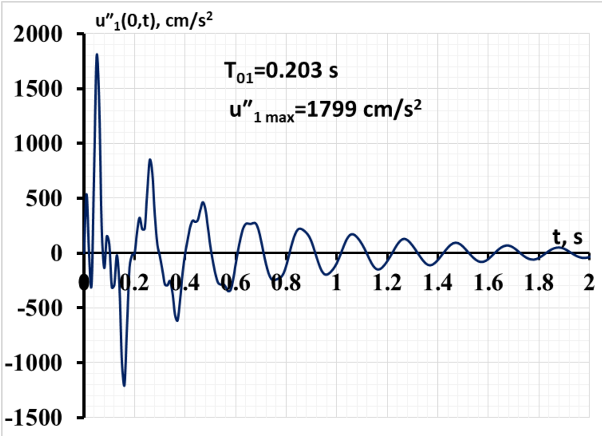

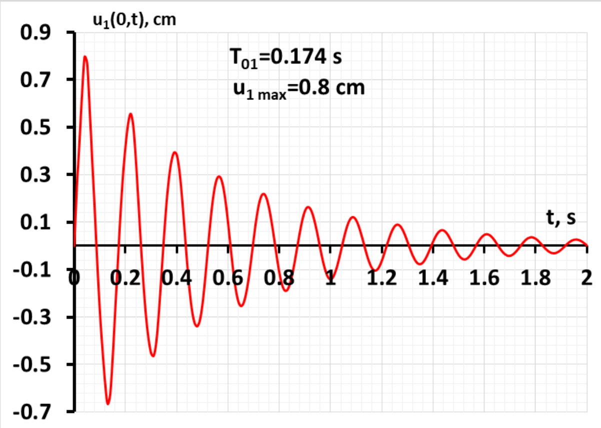

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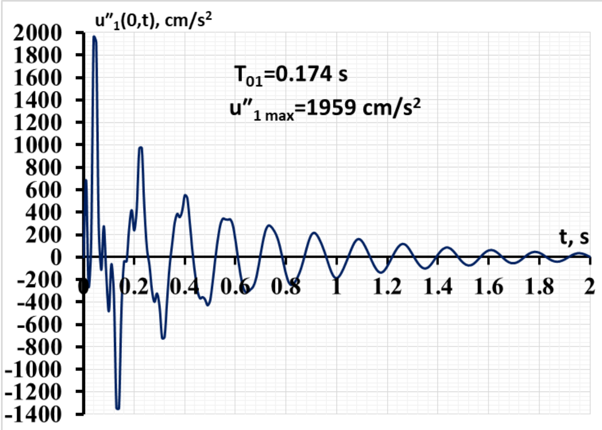

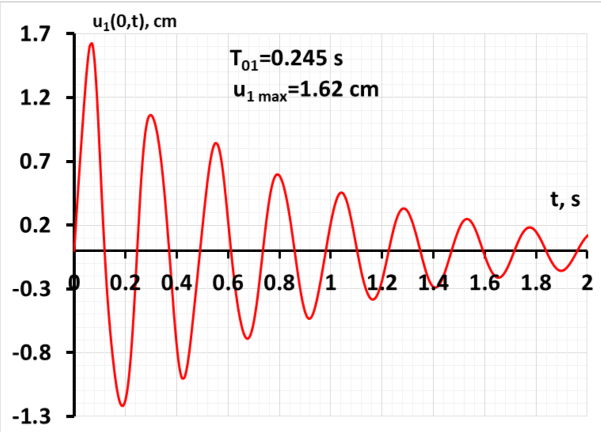

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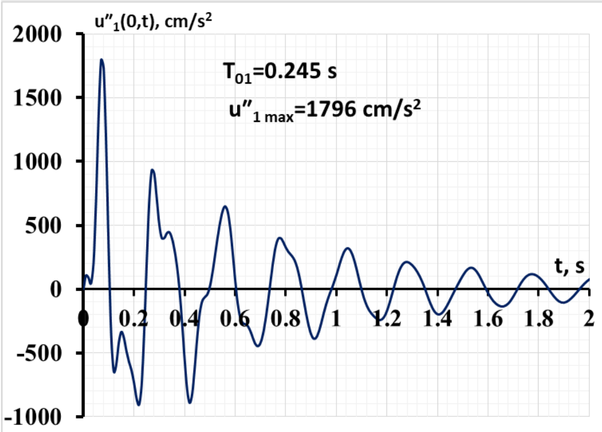

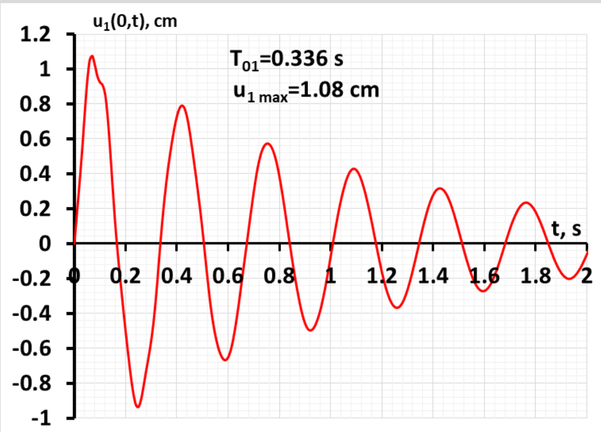

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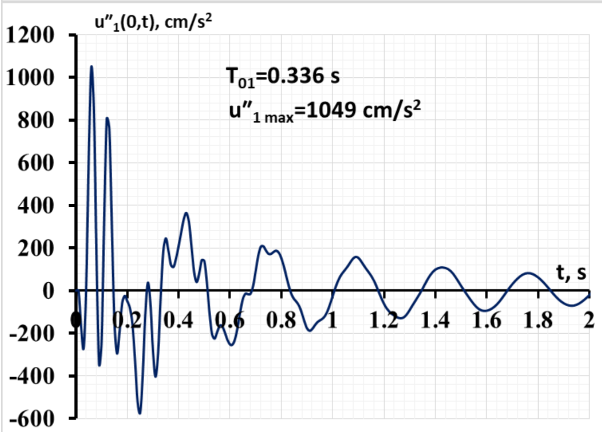
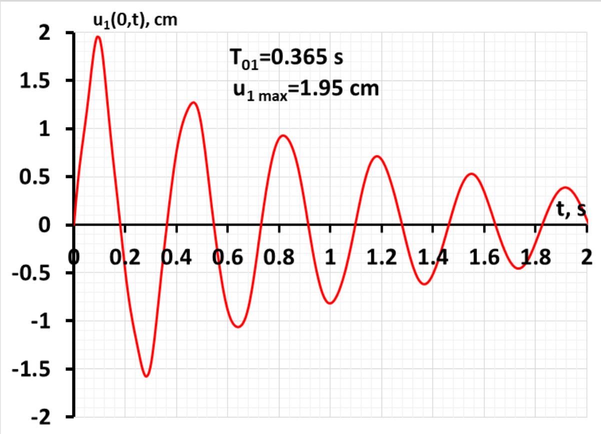


Fig. 5. (continued)



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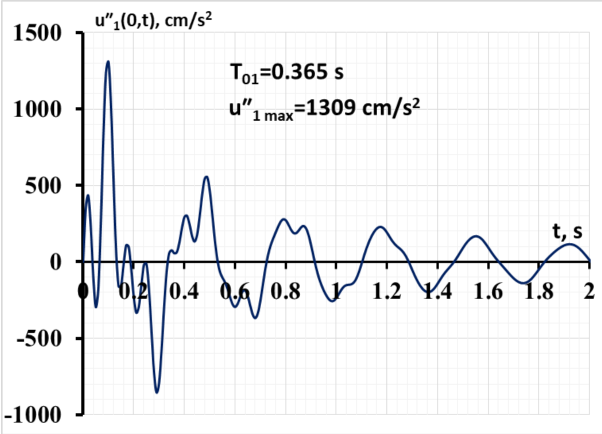

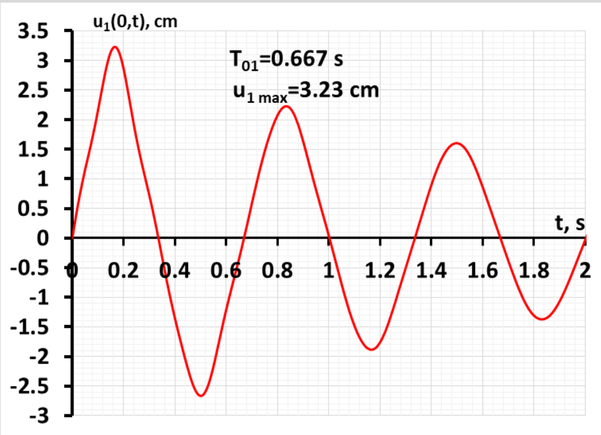

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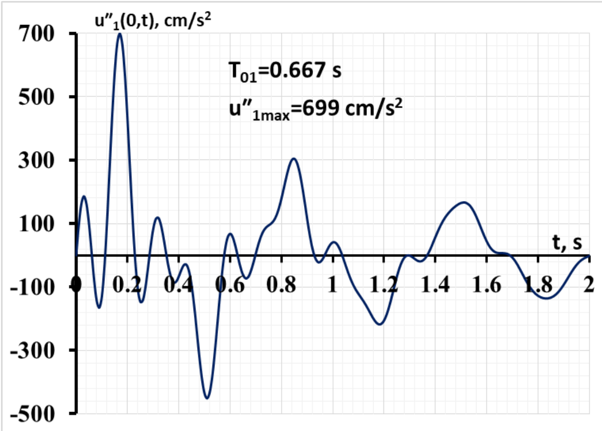

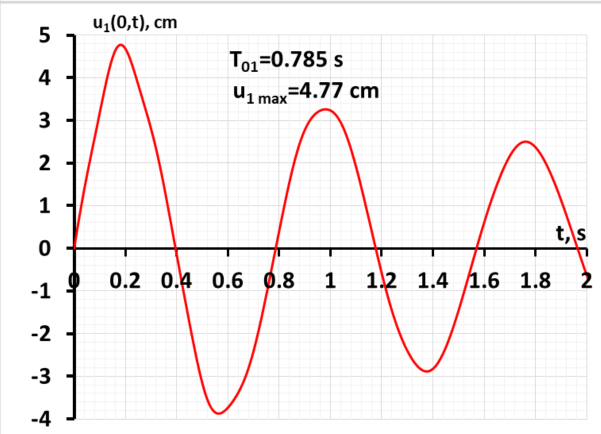

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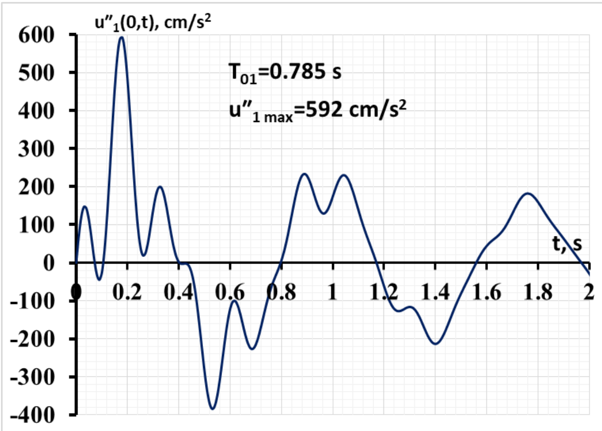

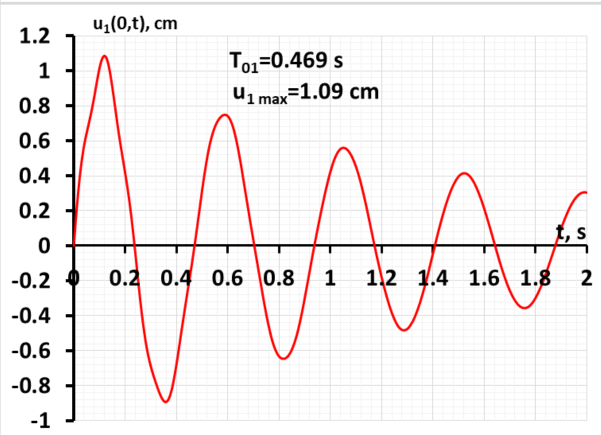

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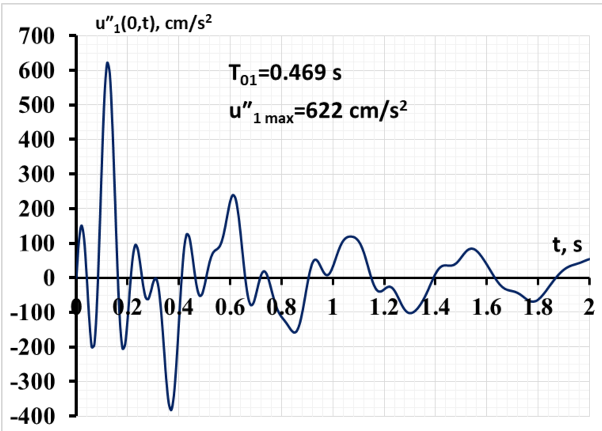

Conclusion

The article develops a method for predicting seismograms and accelerograms for heterogeneous foundation beddings with known physical and mechanical characteristics of the bedrock layers, depending on the earthquake magnitude M≥6.0 and the distance of a given construction site from the fault line. For 16 typical two-layer beddings in soils of various seismic categories, seismograms and accelerograms were obtained for M=7.0 and distance from rupture line Δ=15 km. A method is suggested to replace heterogeneous foundation beddings with equivalent homogeneous ones and quantitative estimates of such replacements are derived. It is shown that the fundamental oscillation mode period T_{01} of the actual heterogeneous bedding changes (both increases and decreases) on average by 1.5 times, whereas the second and third oscillation mode periods on average by 1.3, and 1.05 times, respectively, compared to the periods of the second and third oscillation modes of the heterogeneous bedding. It should be noted that with such replacements there could be an increase in ground accelerations up to 1.6 times. Calculations for the equivalent homogeneous bedding that consider five oscillation modes instead of three, show ground acceleration decreases up to 1.3 times. It has been found out that heterogeneity of the foundation bedding, in fact, leads to increased acceleration and displacement values at the ground surface due to a significant change in the modes of dynamic deformation of the medium (the function $U_{ki}(z)$ and coefficients δ_i) compared to the homogeneous beddings.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

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NEW PERSPECTIVES FOR YEREVAN'S CIRCULAR GARDEN IN VIEW OF THE ENVIRONMENTAL TRANSITIONAL CHALLENGES

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Abstract: *Through the TACEESM research, a meta-design approach is focused on the factors influencing the "reasons and design forming factors of the project" for urban historical/contemporary urban heritages. The goal is to investigate the possibilities of working through mending and regenerative actions in view of the multiple environmental transitions and sustainable challenges. The methodological approach was assessed through a meta-design experimental workshop on Yerevan's Circular Garden. The approach integrates innovative scenarios, visions, and concepts in an inter-systemic method to rethink the urban habitat in an adaptive/co-evolutionary sense, re-establishing relationships, processes, and performances between nature and artefacts, as well as the psychological development level of current society. The experience showed the possibility of repositioning the green heritage design as a process of "mediance" through the techno-sphere, bio/physio-sphere, and anthropo-sphere to support multiple sustainable, alternative, and reversible projects. Considering the green heritage as a space-environmental interface system, it is possible to enable variable adaptative degrees to the different conditions generated from climatic, social, economic, health, and energy transitions.*

Keywords: *Sustainable creative architecture, Meta-design, space-environmental interface, green in-between space, adaptive actions.*

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Received: 27.10.2024

Revised: 19.11.2024

Accepted: 17.12.2024

Introduction

Sustainability challenges, well-being, and urban natural heritage

The concept of landscape with its different degrees of anthropization was defined by the 2000 European Convention[1] as a systemic entity, not confined within dimensional or temporal limitations. Landscape is thus the outcome of a continuous process of interaction between anthropogenic and natural evolutionary dynamics.

Living cultures and cultures of space complement each other, overlap, and sometimes come into conflict. In other cases, they recontextualize themselves by configuring new organisational and functional arrangements to generate positive effects in the balances of settlement space. The definition provided by the *European Landscape Convention* (ELC) is also central in the design process of the urban green heritage to provide sustainable responses in two critical areas: the field of environmental emergencies of energy, land consumption, and reduction of renewable natural resources; the field of emergencies induced by the climate change and the ongoing ecological, economic, and technological transitions. When the ELC preamble integrates perceptual, cultural, economic, social, ecological, and environmental aspects by considering them as "fundamental components of the cultural and natural heritage", a new relational framework through *bios*, *anthropos*, and *techne* is established. A new condition is hoped based on a symbiotic vision of adaptation of humankind to the natural environment. The city's natural heritage can be a regulatory system to foster an ongoing process of human-nature co-evolution that directly affects urban sustainability and people's well-being [1].

Even in urban systems, reasoning on future scenarios of design intervention to safeguard, manage, and plan

[1] Council of Europe. Council of Europe Landscape Convention. As amended by the 2016 Protocol. European Treaty Series - No. 176. Florence, 20. X. 2000.

the natural landscape will therefore have to start from overcoming the unlimited use of existing urban assets in the form of natural, cultural, and social capital.

The natural urban landscape heritage, with its physical identity, loses the connotation of a viewpoint or postcard. Policies that act on the visible natural landscape by acting only on the qualitative composition and re-composition of natural and artificial signs, thus, risk reducing the green heritage to a resource disconnected from the real needs of the settled populations of a city. It is also true, however, that even working on the other identity of the natural landscape heritage, invisible but measurable through environmental performance indicators, is no longer sufficient. There is a risk of transforming the green heritage into a quantitative entity incapable of improving the quality of life and health of the inhabitants.

The prospects for developing the urban green heritage can only start from a reconsideration of the reasons for conservation, enhancement, and transformative interventions. Innovative approaches are needed to manage the increasing levels of complexity of historical and contemporary urban habitats where visible and non-visible landscape aspects coexist. The core of this challenge is interdisciplinary because it is both cultural, behavioural, and perceptual, as well as design, managerial, and technological. A goal would be to find the possibility of working on the urban built and natural environment by pointing out new trajectories of mending and regeneration in view of the multiple environmental transitions taking place.

Actions on the urban green heritage may consolidate the *status quo*, enhance its values, or even radically change its configurational patterns and resource assets to define adaptive conditions of sustainability and well-being of the city users.

In this way, a framework of interventions could be outlined that is no longer circumscribed within net project categories. In an inter-systemic leap, moments of conservative preservation of the natural heritage would alternate with phases of care and innovative actions to produce new values and profitability. This would create the conditions for developing alternative scenarios and multiple visions of coherence between the inhabitants' needs, the environmental context variables, and the diverse levels of ecological, economic, and technological sustainability.

A different conception of the city's natural/artificial assets in the flow of time would thus be placed at the centre of the propositional process. That is, considering these assets not as consumer goods, objects, or products but as capital to be conserved, maintained, and regenerated for present and future generations.

Methods. The TACEESM experience and the Capability Building Approach

Through the TACEESM experience (Transforming Architectural and Civil Engineering Education toward a Sustainable Mode – EU Erasmus+ Program), research units of the University of Chieti-Pescara and NUACA University have developed a meta-design and interdisciplinary methodological approach to focus the complex relationships of the project with historical, modern, and contemporary urban heritages, using a strategical coexistence between mending and regenerative actions.

The TACEESM challenge was to interpret the design process through pre-existences and innovations in the urban field based on a multicultural and poly-disciplinary idea of the project. As multicultural, the project is confronted with its globalised nature and brings with it a continuous exchange of knowledge, contamination of cultures, hybridization across traditional and more innovative knowledge [2]. In its multidisciplinary nature, the project involves a more complex rearticulation between different expert and diffuse contributions, to open to a dialogical confrontation with a framework of "pertinences" through global and local dimensions [3].

This methodological approach was assessed for the first time on the Yerevan *Cascade*. The *Cascade* was considered the best opportunity to check the methodological theoretical issues and design outcomes on a case study with a complex contextual framework of public pre-existences, monumental architectures, natural entities, urban vitality, and cultural-artistic initiatives. The second checking activity was tested on Yerevan's *Circular Garden* through the bilateral agreement for teaching activity, research, education and training program between the NUACA and UniCH-PE universities.

The oppositions between the technical and humanistic dimensions of the project lose their certainty. The human habitat is configurable "not in a naturalistic or aesthetic sense, but in a constructive sense" [4]. According to this point of view, it is also possible to redefine the relationships between conservation, enhancement, and transformation of the urban natural heritage by following heuristic development trajectories based on heterogeneous approaches and tools. Working on urban natural heritage becomes design research on the "reasons of the project", crossing multiple levels and timescales of intervention through strategies of conservation, care, and valorization of the built and natural resources.

The experimental approach developed in the TACEESM initiative makes it possible to enucleate at least three different fields for these project reasons by placing them in a design process that operates synchronically and diachronically on the capacities/abilities (capacity building approach) that can be activated for the sustainability of the urban habitat[2,3].

A first field concerns the ability to problematize the project. This means being able to see, listen, and detect the real needs for transformation of the urban habitat and its natural heritage, according to the needs of its inhabitants and users. The project is no longer unidirectional but opens itself to a framework of shared, combinable, or reversible scenarios, recording experiences, causes, effects, feedback, interferences, unforeseen events that can connote intervention on the natural heritage, not as an arbitrary action.

A second field relates to the development of distinctive design visions working with pre-existences, care-oriented or toward innovation too. Through visioning, plural and a-scalar perspectives of intervention on the urban natural heritage are enabled. By breaking the unidirectional sequence that goes from the general aestheticizing representation to the technical details of the project, more alternatives focus on the different quality levels of urban living with natural resources.

A third field refers to the capability to translate the knowledge that can inform the various project implementation phases on the urban natural heritage in the short, medium, and long term. The design experience is not limited to providing closed solutions but becomes a cognitive process of analysis, forecast, projection, and verification of its degrees of feasibility and evolution. The project extends to conceptualise the contents of interventions for the sustainability of the city, acting on urban natural heritage.

From scenarios to visions, to concepts

The capacity-building approach applied on the *Circular Garden* case study was tested as part of a meta-design process in which researchers, teachers, students, and users/inhabitants were involved. The starting assumption is to overcome the idea of urban public space (with its natural and built heritage) based on the distinction between context (external environmental system), container (built heritage/environment), and content (natural heritage, inhabitants/users, technical objects/equipment). In the public and collective spaces of contemporary cities, environmental, social, economic, common, and individual dimensions coexist in a space-time *continuum* with very blurred contours definable as an urban space-environmental interface system. In this urban space-environmental system, natural heritage is also a wide regulatory interface that acts on cultural, behavioural, perceptual, ecological, socioeconomic, and decision-making dimensions to improve the conditions of living the city together[4,5]. The city's unbuilt green and natural space has thus been taken as an intermediate system for extending the degrees of interaction and adaptation among urban components. This position allows alternative context-sensitive and responsive sustainability futures to be defined even by bringing inhomogeneities, anisotropies, and discontinuities.

Through the capacity-building approach, multiple conditions for the regeneration of the *Circular Garden's* natural heritage were explored according to different intervention modes from both user-centred and

[2] United Nations, Transforming our World: the 2030 Agenda for Sustainable Development, UN A/RES/70/1. sustainabledevelopment.un.org, Distr.: General 21 October 2015.
Available at: https://www.un.org/sustainabledevelopment/development-agenda/

[3] UNESCO, Policy Document for the Integration of a Sustainable Development Perspective into the Processes of the World Heritage Convention, 2015, General Assembly of States Parties to the World Heritage Convention, 20th session.

[4] UNESCO, Recommendation on the Historic Urban Landscape adopted by the General Conference at its 36th session, Paris, 2011, 3.

[5] UNESCO/ICCROM/ICOMOS/IUCN, Guidance and Toolkit for Impact Assessment in a World Heritage Context, UNESCO, Paris, 2022. Available at: https://whc.unesco.org/en/guidance-toolkit-impact-assessments/

environmental-centred perspectives[6]. The meta-design process thus took on a technological-environmental dimension. With respect to the areas of environmental, economic, and social sustainability/compatibility, the green assets of the *Circular Garden* were assessed in their variable anthropological, topological, and technological dimensions. Ten recurring systems of natural and artificial entities that interact with the green heritage from outside, through, and within were considered. The ten systems relate to: actors (users/inhabitants), natural and artificial factors/agents, activities and functions, spaces and places, times and cyclicities, ways of using space, causes, means, and tools, fixed and variable contextual quantities, technical systems, and objects.

The final meta-design exploratory framework is characterised by the reiteration of key issues/questions concerning who/what acts, where, how, when, why, by what means and with respect to which entities in the development of the scenarization, vision, and conceptualization activities (Fig.1). Through this process, the urban natural heritage interventions do not exclude the measurability of the project's responsiveness to users' needs or to the conservation and transformation policies. At the same time, we do not lose sight of the multiple configurations that the contemporary green heritage may assume in the short, medium, and long term. The meta-design experience based on the capacity-building approach makes it possible to go beyond the forecasting-based practice of "what" will happen in the city's natural spaces. The natural heritage becomes central for a multidimensional experience that extends itself to get alternatives for the future through foresighting and backwarding on the reasons for the various levels of intervention.

Issues/Questions	Anthropological dimensions	Topological dimensions	Technological dimensions
WHO uses the green space?	numbers and typology of users/inhabitants	users'/inhabitants' typology related to natural agent/factors	other specifical users (for maintenance, security, temporary working)
WHAT forces interact with the green space?		sun, shadows, wind, water, humidity, noises, traffic positive/negative interactions (eventually also animals)	eventually artificial entities (cars, bus service, technical machineries)
WHAT users do in the green space?	kind of actions/activities of users/inhabitants	positive/negative reactions of users/inhabitants to sun, shadows, wind, water, humidity, noises, traffic, (animals)	eventually activities (positive/negative) related to the technological entities
WHERE are activities developed?	distributions of users/inhabitants presence	users'/inhabitants' activities influenced from sun, shadows, wind, water, humidity, noises, traffic, (animals)	
WHEN is the green space used?	time extension of actions/activities	effects of sun, shadows, wind, water, humidity, noises, traffic, (animals) on the times of use	effects of technological entities on the times of use
HOW is the green space used?	practices and behaviours of users/inhabitants	users'/inhabitants' behaviours modifications related to sun, shadows, wind, water, humidity, noises, traffic, (animals)	users'/inhabitants' behaviours modifications in presence of artificial/technological entities
WHY is the green space used?	users'/inhabitants' needs	attractiveness produced from sun, shadows, wind, water, humidity, (animals) (also why the green space is not used?)	attractiveness of artifacts and eventually technological entities
WHICH kind of tools are used?	kind of devices and prosthesis	users'/inhabitants' tools/devices to protect from sun, shadows, wind, water, humidity, noises, traffic, (animals)	users'/inhabitants' tools/devices necessary to use artificial entities
WHAT is the amount of used green space?		main/preferable used areas	main/preferable used areas in which is relevant technological entities
WHAT entities define the green space?		relations between building/infrastructures and sun, shadows, wind, water, humidity, noises, traffic, (animals)	eventually important artifacts (e.g. pavilions, built objects, furniture, technical plants)

Fig. 1. *Explanatory framework of key issues/questions considered for the assessment of anthropological, topological, and technological dimensions influencing the urban green heritage as a cross-system regulatory interface. Source: authors*

The meta-design process experimented on the *Circular Garden* was developed in three closely interconnected phases through a continuous monitoring activity of the decision-making and projective

[6] United Nations, Convention Concerning the Protection of the World Cultural and Natural Heritage, WHC-11/35.COM/9B, Paris, 2011, United Nations Educational, Scientific and Cultural Organization.

coherence levels between scenaristic-strategic, visionary-tactical, and conceptual-operational aspects.

The aspects of strategic-scenarization, foresighting, and backwarding activities made it possible to extend the meta-design exploration to the possible configurational patterns of the *Circular Garden* system and subsystems. The following aspects were synchronically/diachronically brought into play: physical-material entities (actors, animals, context factors, objects), material connections (processes, supply chains, cycles), established and new functional challenges (daily and tourist uses, sharing, cooperation), traditional or innovative intangible relationships (communications, events, performances). The development of the visioning allowed the elaboration of projective anticipations on the evolution of the *Circular Garden* by considering process, performative, and relational variables that allow the role of the natural heritage to still be unchanged or that are also changing. We have thus focused on the main metamorphosis vectors that, also in a tactical-alternative way, make the *Circular Garden* assume more degrees of performance redundancy and regulatory-adaptive capacities of resilience, antifragility, inclusiveness, vitality, smartness, healthiness, environmental integrated accessibility.

Conceptualization aspects favoured the development of content to address the intervention quality not only in morpho-generative terms, but also in an eco-relational sense between natural and artificial urban spaces. Priority concepts were then defined to: produce, maintain, and regenerate natural resources essential for urban life (ecological-spatial concepts); innovate uses and modifications of the commons resources compatible with inhabiting-building cultures (economic-spatial concepts); interface physical, connective, and functional variables to mediate anthropic-natural evolutionary dynamics (transitional-spatial concepts).

An experimental approach between Sustainable Creative Architecture and Meta-design

While discussing the scope of factors that should be considered in the architectural design process, there is one more important factor influencing that process. It is the "source" of that design, e.g., an architect or any author with a complex of his/her level of development, self-identifying and creative intelligence. Elements such as psychological background, upbringing, education, national identification, understanding of happiness, etc. are the key points of the author, and significantly influence and are interconnected with that "source". Consequently, these variations in personal characteristics, the different "levels" of those criteria can profoundly impact the final design outcome. At the National University of Architecture & Construction of Armenia (NUACA), we emphasize that being an architect transcends mere professional choice; it embodies a lifestyle commitment. Architects must find joy in their work, as the designs they create should emerge from a point of fulfilment and happiness. In this context, the TACEESM program has introduced a unique infographic methodology during workshops held in Malaga and Yerevan. This approach was spearheaded by the "Shatvoryan School of Architectural Self-Development", since its inception in 2019, in the frame of architectural workshops. This methodology involves sketching while listening to music, learning tolerance, being self-sustainable with no distraction, and engaging in several exercises, beginning with a "free" topic to relieve psychological tension. This is followed by more focused sketching on specific themes, leading to collaborative efforts. The culmination of these activities is the exploration of a key topic, in our case, reorganizing public spaces in Yerevan, specifically the design of the *Circular Garden*. The methodology completely lies down with the multi-layered approach, which reflects a deeper understanding of the architectural process. The method has been repeatedly tested through design workshops, consistently demonstrating that those who engage in the preliminary "tension-releasing" exercises generate more innovative and thoughtful designs compared to those who dive straight into assignments. For architects and designers, being mindful of their emotional and psychological states is essential. Such awareness can greatly enhance their capacity to find creative solutions, ultimately leading to more impactful and meaningful designs.

The key actions of the Yerevan Circular Garden experimentation

From the point of view of urban sustainability and inhabitants' well-being, acting from a technological-environmental meta-design perspective means framing actions on the city's green heritage by confronting different orders of problems and reasons for the project. The analysis, scenarization, visioning, and conceptualization steps were so oriented toward a holistic signification of the natural heritage urban role going beyond the classic three dimensions of ecological, economic, and socio-cultural sustainability [5].

By providing for participatory/inclusive preparatory and monitoring actions that may support the various steps of urban natural heritage development, the meta-design path could give the institutional bodies (e.g., universities, public administrations, associations, etc.) a new role as an enabler/facilitator actor for the achievement of the urban sustainability and well-being goals.

The Circular Garden between Tamanian's plan and Yerevan sustainability

Before delving into the topic of designing green and open public spaces, it is important to discuss the example of our study, specifically the creation of a circular garden around the small center of Yerevan by Alexander Tamanyan. Tamanyan, the architect of the city, was inspired by the principles of the "garden city" concept introduced by Ebenezer Howard [6], which emphasized the importance of a well-defined city centre surrounded by accessible green spaces and streets, often referred to as the "lungs" of the city.

While Howard's ideas did not specifically call for circular forms, Tamanyan [7] envisioned the city centre as an amphitheatre nestled between hills, offering a view to the south and Mount Ararat, a sacred symbol for Armenians. This unique design choice created a harmonious and visually appealing urban landscape.

Our study focuses on the eastern part of Yerevan, extending from North to South. As the city's population grew from 30,000 to 150,000 and beyond, Tamanyan recognized the importance of incorporating green spaces within reasonable reach for residents [8]. Unfortunately, the architectural development of the city was hindered by historical, political, and socio-economic challenges during the post-Soviet era. These factors have impacted the city's architectural evolution and the realization of Tamanyan's vision for a green and vibrant urban environment.

Scenarios: an open project for the city's natural heritage

Scenario projections concerning the city's natural heritage as a regulatory space-environmental system should develop beyond the simple strategic-programmatic level. A system of natural heritage interventions should enable the evolution of urban green resources by supporting them toward the different community's needs. During the Yerevan *Circular Garden* experimentation, the natural heritage was considered in the urban system extended in space and time, investigating the so-called buffer zones and the field of interactions with the city's extended context. Scenarization was confronted with the key issue of foreseeing the conditions that can, could, or should not occur in the *Circular Garden* to preserve its particularities and functions. The different sections of the *Circular Garden* were studied by considering: the analysis of the extended reference contexts (e.g. SWOT analysis, questionnaires, individual and shared storytelling, documental and photograph archives); agents and determinants of well-being and living quality (e.g. sunshine factors, ventilation, temperature variations, precipitation, humidity, noise levels); the extension of natural/artificial surfaces, masses, and voids involved in the different sections (e.g. trees, technological systems, technical objects, buildings, infrastructures, collective spaces); the study and evolution of users'/inhabitants' different practices and behaviours (e.g. needs system, interviews, on site surveys, activities-functions maps, space-functional compatibility/incompatibility framework, space correlation framework, urban sketching, mind mapping). The emergent framework (Fig.2) is not limited to drawing only predictive scenarios in continuity with the past[7]. Probable scenarios (in line with trends/mainstreams), plausible scenarios (foreseeable), possible scenarios (not entirely foreseeable) and even scenarios that absolutely must be avoided (unsustainable, absurd, or dangerous) have been projected.

A comparative strategic framework was so defined to confront levels of intervention based on different green intensive actions.

Visions: The Circular Garden as a green in-between system for Yerevan

Configuring the *Circular Garden* natural heritage according to sustainability and urban well-being goals

[7] United Nations, World Cities report 2022. Envisaging the Future of Cities. Nairobi, UN-Habitat, 2022. Available at: https://unhabitat.org/world-cities-report-2022-envisaging-the-future-of-cities

means imagining a space-environmental system in which several levels of systemic interaction between natural, cultural, economic, and social capital coexist[8]. Through the meta-design process, the priority goal is to translate the scenario hypotheses into alternative patterns of the space-environmental system. This means to project tactical and reversible visions in which all urban components can contribute to defining adaptive and co-evolving mediating arrangements through nature, society, individuals, and technologies, assuming the role of central fundamental resources for the city's sustainability and wellbeing[9] [9].

Strategies toward more green intensive actions	what can happen		what could happen		what should not happen
	Predicted scenarios	Probable scenarios	Plausible scenarios	Possible scenarios	Unsustainable scenarios
Transforming park hypothesis	Chaotic development of actual compresence of natural heritage and artifacts	Intensification of micro-building and artifacts colonization	Circular Garden as walking path between architectural promenade	Circular Garden temporary empowerment with provisional micro-architectures	Micro-insula effect with total fragmentation of Circular Garden
Rainbow hypothesis	Separated development of 4 main Circular Garden existing functional sectors	Hyper-specialization of 4 existing Circular Garden sectors	Circular Garden as continue green path connecting 7 thematic functional areas	Total reconnection of 7 thematic areas, disrupted areas and Getar river course	Insula effect and demi-privatization of some Circular Garden existing sections
Reviving memories hypothesis	Overlapping of new functions to maintain the urban role of Circular Garden	Loss of memories and traditional aspects related to the story of Yerevan	Circular Garden as park/path of cultural and architectural memories	Soft micro-artifacts to transform the Circular Garden in open-air green history museum	Total loss of Tamanian's green plan pattern and globalization of Circular Garden
3R (reconnective) hypothesis	Functional loss of open air public and private activities	Intensification of building development and functional fragmentation	Circular Garden as urban green connectors for visual, physical and seasonal uses	Soft micro-intervention to supply the re-connecting function according to emerging needs	Total separation in 7 independent sectors and green as building service area
Green river hypothesis	Continuation of melting-pot practice development between green heritage and small buildings	Maximum extension of buildings and open-air recreational infrastructures	Circular Garden as urban green/blue infrastructure through intensive greening actions	Circular Garden also as blue infrastructure trough water patch-areas insertions	Total loss of green heritage as result of probable scenario
Wall of trees hypothesis	Total separation in 7 independent sectors and green as building service area	Totally autonomation of functional sector from Yerevan life (Luna-park effect)	Circular Garden as Tamanian's original experience park inside the green	Totally remotion of furniture and artifacts, Circular Garden as open-air urban green-repository	Progression of green disruption as result of probable scenario

Fig. 2. *Comparative strategic framework with multiple scenarios and distinct levels of green actions. Source: authors*

Urban natural heritage can no longer be considered part of the bio-physio-sphere between buildings nor part of nature-containing entities belonging to the anthropo-sphere or techno-sphere. What appears is a hybrid conception of the natural heritage as a green in-between interface system that involves the entire settlement and its inhabitants in a field of inter-systemic reactivity in which quality must be at once ecosystemic, housing, constructional, and managing. In these terms, the Circular Garden visioning activities were developed by prefiguring spaces according to quality macro-requirements to meet the challenges emerging from the new paradigms of environmental sustainability and people's psycho-physical well-being. The idea of quality was declined through different degrees of intervention in the green heritage (Fig.3):

- As a relational quality to harmonise the ecological-environmental interactions between natural and artefacts, increasing the resilience/anti-fragility and healthiness of the city and its inhabitants.
- As process quality, to coordinate the natural/technical resource use, transformation, and management, increasing the conditions of smartness/interactivity and inclusion/participation for all.
- As performative quality, to orient the care, preservation, and transformation of natural/artificial systems by improving the conditions of vitality/identification and accessibility of/to the resources.

[8] Green City Network, Green City Guidelines. Green City Network, Rome, 2018.
Available at: https://www.greencitynetwork.it/wp-content/uploads/Green-City-Guidelines.pdf

[9] World Health Organization, Green and Blue Spaces and Mental Health. New Evidence and Perspectives for Action, Copenhagen, WHO Regional Office for Europe, 2021.
Available at: https://iris.who.int/bitstream/handle/10665/342931/9789289055666-eng.pdf?sequence=1

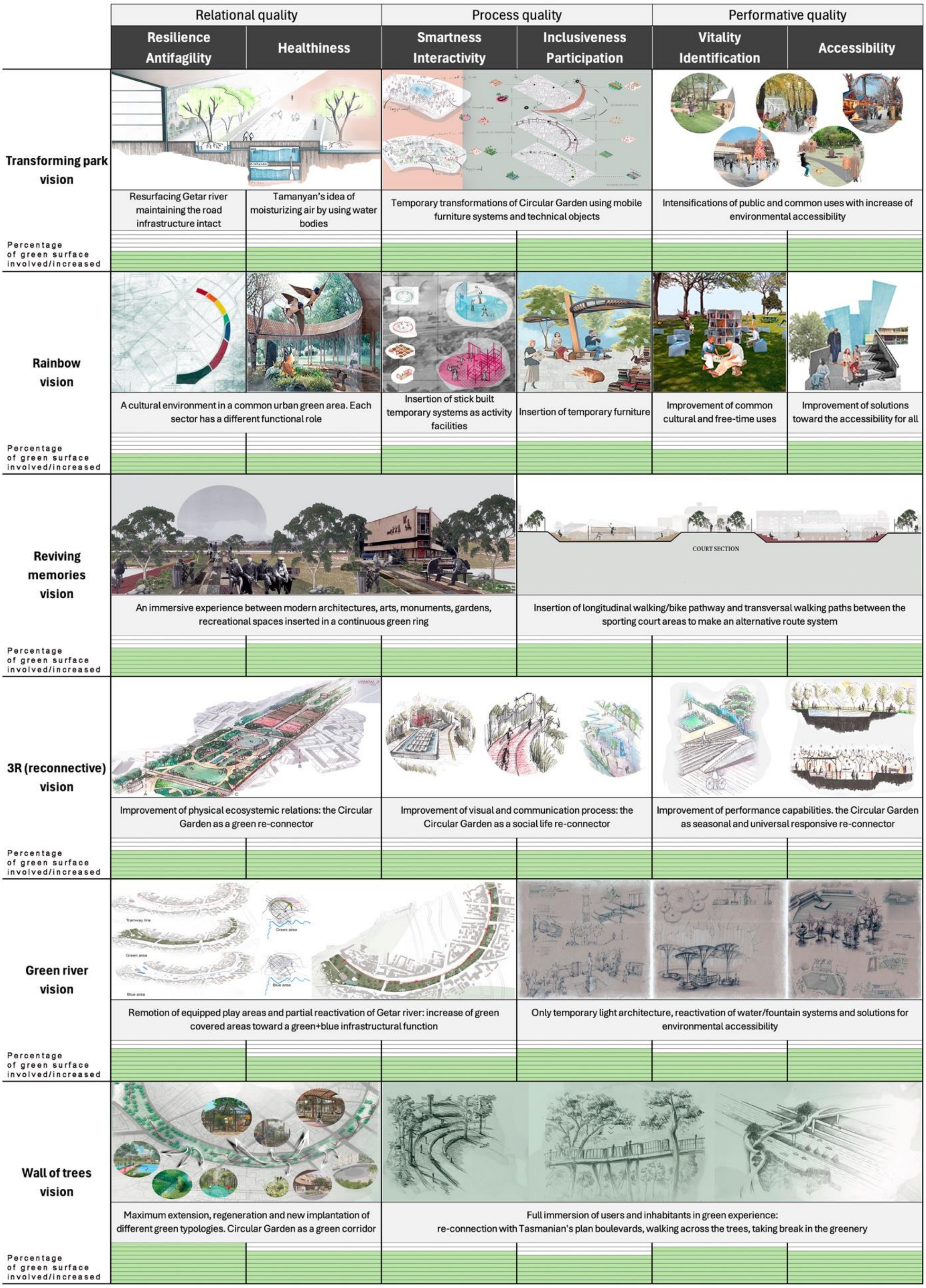

Fig. 3. *Visioning framework related to the degrees and typology of intervention on the green heritage: each vision considers different relational, process, and performative qualities issues and macro-requirements referring to the sustainability and well-being goals. For each vision, it is shown a qualitative pre-evaluation of percentage amount of green surface involved. Source: diagram elaborated by the authors starting from the experimental workshop results*

Concepts: New kind of green in-between spaces

Through the conceptualization phase, the urban natural heritage can be defined as a green in-between system to activate and regulate interactions through dynamical uses, functions, economical, and productive processes. The main challenge of this step is to avoid formalistic figurations focused on a concept/image that linearly could transform itself into a closed project. Meta-design conceptualization makes it possible to translate the information content (i.e., data, information, knowledge) generated through the analysis, scenarization, and visioning into an inform-actional (informative contents toward implementable actions) dimension. With the conceptualization, two important and fundamental challenges are addressed.

First, it is possible to outline the priority contents of the project to maintain, regenerate, and reinvent the values and meanings of the natural heritage toward the shared goals of sustainability and well-being.

Secondly, necessary criteria requirements are set up to direct the urban natural space-environmental system toward multiple adaptive alternatives.

The outcome of this activity shows the possibility of working on the urban natural heritage according to a continuous and open project involving all the biotic and abiotic components and capital (natural, human, socio-cultural) of the city [10,11]. At the same time, there are opportunities to work on the urban green in-between system in diverse ways. Starting from minimal care, reuse, and maintenance interventions, it is possible to go on toward more incisive actions of restoration, regeneration, or even densification of the green system, in a mix that always oscillates between conservation and transformation [12]. In the experimentation conducted on the *Circular Garden*, conceptual meta-design made it possible to recognise the genotypic richness of the urban natural heritage and its capability to generate multiple phenotypic forms of adaptation to respond to the metamorphosis of the city-system.

The emerging concepts of this third meta-design phase envisage non-linear actions acting on several levels and scales, according to the principles of interactive implementation [13]. Concepts could be no more exclusively related to specific scenarios or visions but can support the co-evolution of the *Circular Garden* system through a synergic combination of planning, design, implementation, and maintenance, allowing the natural heritage to take on varying patterns (promenade cross-sections) according to the contextual environmental changes (Figs. 4.1/4.2).

Results and Discussion

The results of the *Circular Garden* workshop experience show the opportunity offered by the meta-design process to reposition the project on the urban natural heritage within a broader vision of the built environment. Working in an a-scalar and transversal sense, it is possible to project multiverse trajectories (*trajection)* of "mediance" [14] through the techno-sphere, bio/physio-sphere, and anthropo-sphere between technologies, nature, society, and people. The meta-design process overcomes the modern dualisms subject-object or conservation-*tabula rasa*; it can support the development of sustainable and well-being-oriented alternative urban project trajectories acting both on natural, human, and cultural capital.

The goals of sustainability and well-being also become decisive in the design of natural heritage for two other aspects. The first aspect concerns the possibility of considering well-being in a capability-empowering sense. Well-being cannot be separated from sustainable actions aimed at reducing land-soil consumption, maintaining and regenerating the green heritage, reducing water consumption and climate-changing emissions, safeguarding the reproducibility of living species[10]. The second aspect concerns the need to reinterpret the well-being as "well living", in the sense suggested by Edgar Morin [15]. In any case, all project experiences can contribute to the search for relevant knowledge to acquire skills for living in society and cities.

Within this reference framework, the results achieved through scenarization, visioning, and

[10] Stockholm Resilience Alliance, Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners. Revised Version 2.0., Resilience Alliance, Stockholm, 2010.
Available at: https://www.resalliance.org/files/ResilienceAssessmentV2_2.pdf

conceptualisation show how a good meta-design process can contribute to the definition of various actions aimed at rethinking the *Circular Garden* as a space-environmental system of regulatory interface considering:

- The *Circular Garden* as an urban natural historical heritage, conceived in the past to ensure in Yerevan better liveable conditions and qualities of life, and which can evolve toward new qualitative declinations of living together in the city.
- The *Circular Garden* as an infrastructural system projected toward medium and long-term intragenerational and intergenerational sustainable goals, in which the natural heritage is confronted with the new paradigms and challenges of sustainability.
- The *Circular Garden* as system aimed at the maintenance, development, and co-evolution of people's well-being conditions in the short and medium term, considering the different variables and transitions that can affect the inhabitants' health.

Planning	Design	Implementation	Management
Integrability. Circular Garden to reprogram as green promenade reintegrating the tramway lines on 2 external sides of the park.	**Connectivity.** Intersections between Circular Garden and transversal urban roads to improve the reconnection of green continuity through ecoducts (on surface level) and road deviations (on underground level).	**Green continuity.** Recreational temporary/unused pavilions to remove toward the recovery and maximization of green coverage continuity also through new trees insertions.	**Densification.** To promote only intervention of re-densification and re-integration of trees, shrubs, herbs coverage also supported through the remotion of temporary pavilions and eventually extraordinary demolition of unused buildings.
Blue infrastructurability. Rediscovering of Getar river course in all those situations where is possible.	**Walkability/Cyclability.** Entire length of the Circular Garden to transform in a promenade with walkable/cyclable paths between the urban green.	**Slow-mobility.** For the achievement of urban slow mobility, introduction of a light low speed micro-people mover along all the new Circular Garden promenade.	**Soil permeability.** Existing walkable paths to transform in hybrid drainage/storage rainwater infrastructure to improve multiple use of water (e.g. irrigation, reactivation of winter skating rings, regulation of humidity, reuse of rainwater).
Health orientation. Circular Garden promenade to re-develop toward a cultural, sport-well-being and therapeutical activities for a total immersion into natural open-air spaces.	**Interaction empowerment.** Insertion in the Circular Garden promenade and on road intersections of suspended walkable path for all to improve the experience to live between the nature inside the city.	**Multi experience-ability.** Isolation of the Circular Garden from the urban surround for a continuous green-wall promenade to create experiential conditions of forest-scape, soundscapes, flavour/olfactory-scapes, waterscapes.	**Transformability/Reversibility.** Only temporary soft/light use connected with cultural, educational and musical activities must be previewed for the Circular Garden using removable furniture, pavilions, plants.
Alternative movability. Introduction of a bicycle line inside the garden to promote alternative moving modalities across the city, using shortest route through the Circular Garden.	**Permeability.** Redefinition of the Circular Garden central sectors through the introduction of walkable public pathway crossing the private sporting areas.	**Soil re-reshape-ability.** Sporting courts to transform in public playgrounds and to redefine under the road level improving better audience and visibility from the garden at street-eye level.	**Removability.** Remotion of recreational, carousel, and restoration buildings preserving only cultural architectures and monuments.
Water permeability. Getar river to re-surface without removing road infrastructures re-establishing balanced conditions between air and water and proper irrigation conditions for the green areas.		**Micro-climatic adjustability.** Support new tree planting to put the Circular Garden at least toward the 10% of Yerevan built up areas and to improve urban microclimatic regulations against heat-island, dust, smoke, and noise.	

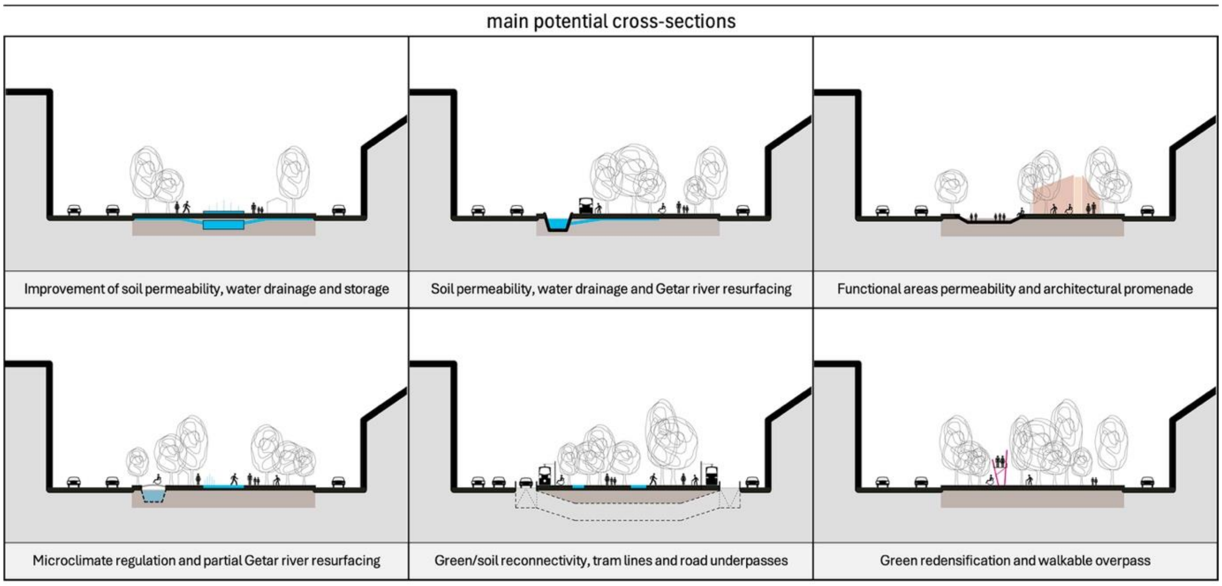

Fig. 4. | *4.1 – Example framework of conceptualization outcomes as criteria-requirements referring to the main steps of interactive implementation process; 4.2 – Comparison framework between various potential Circular Garden cross-sections. Source: authors*

Green in-between spaces as opportunity to re-capitalize the urban landscape

Through the interpretation of the natural heritage as a complex system of ecological, anthropic, and cultural resources, the *Circular Garden* is assigned a strategic, tactical, and operational value to accommodate caring, ideational, and productive activities to the various forms of urban capital. We therefore go beyond the ideological-financial vision of natural heritage as a system of consumer goods that can be monetised. The hypothesis is to place the *Circular Garden* in a new value, economic, and regenerative dimension. The green in-between system is recontextualized within a dual horizon of recapitalization.

On the one hand, the *Circular Garden* can contribute to recapitalizing and enhancing the value of the natural heritage (reproducible green capital) with other functional, performative, and relational meanings (shareable socio-cultural capital) concerning the values attributed to it by users and inhabitants. The perception, cognition, and experience of the *Circular Garden* arise from the connections that will be established with the change of actors who live and work in it, in terms of using benefits, safety conditions, affordances, accessibility to resources, common services, identification of existence, and survival spaces. Assuming not only an ecosystemic but an ecological-cognitive value as the result of an integrated eco-socio-technical process, the *Circular Garden* will thus play the role of an interface landscape in which different modes of connection between living organisms and resources, between human societies and nature are manifested [16]. It may also take on value as a landscape whose "third" nature [17] will allow some parts to be preserved and maximised as purely natural resources for the sustainability and well-being of Yerevan.

On another line of recapitalization, the *Circular Garden* reinterprets the system of natural resources in an innovative way, considering them no longer as background goods (i.e., as objects/tools dedicated to production processes). The background goods are also given technological, environmental, and cultural value for the economic activities in which the aesthetic, formal, and expressive canons of a community are reflected. The *Circular Garden* is therefore a semi-natural heritage system that holds a space-territorial dimension, requiring care, maintenance, conservation, or even redesign to preserve its form and functionality. Focusing on the forms and functions it has taken and will continue to take over time, the *Circular Garden* thus becomes a natural, architectural, artistic landscape in which biological, technical, cultural, and material resources coexist [18]. It loses its nature as an instrumental entity to be exploited (immobilised physical capital) and is identifiable as a system of spaces and places (transmissible physical-cultural capital) in which each activity can contribute to maintaining or modifying the city's states of sustainability and healthiness.

From this experiment, therefore, the *Circular Garden* appears as an ecosystem connected with cultural, functional, and economic values, manifesting itself as a system of immaterial and intangible values. At the same time, however, it is as a system of public works, architecture, landscapes, and resources with their own tangible, material form and consistency. The qualities of this heritage should therefore be considered dynamically, enhancing the potential degrees of responsiveness and adaptability to internal and external stresses as fundamental resources for fostering Yerevan's sustainability and well-being.

Conclusion. Circular Garden as a new potential connector of sustainability and well-being

Technological innovations have allowed us to determine well-being, safety, and sustainable-oriented conditions inside the capsular artificial realities of buildings. But what happens outside in the urban space when we consider the natural resources?

The outdoor urban environment, where nature interacts not only in parks and gardens but also with streets and squares, can contribute to declining sustainability and well-being by extending the definition of heritage or landscape. It is so important to explore the different fields of conservation and transformation that may arise under conditions of environmental transition between the more stable long-term projections and the more immediate and executive mid/short-term actions. Urban natural heritage projects top-down imposed or theoretically unchangeable risk to become inadequate or ineffective.

The capacity-building approach experimented on the *Circular Garden* involved in an inter-systemic process innovative scenarios, visions, and concepts enabling the rethinking of urban natural heritage in an adaptive/co-evolutionary sense, re-establishing relationships, processes, and performances between nature and artefacts. From this meta-design experience, a new idea of project emerged; it is referable not on authorial, predictive, or blocked positions acting on objects and parts of the city. Key sustainability challenges require a design process that works on intermediate space-environmental systems of systems. The role of these interfaces is to enable multiple degrees of variable adaptation with respect to global and local conditions induced by environmental, climatic, social, economic, health, and energy transitions.

Considering the extension and the complex pattern variability of the *Circular Garden* as an *ante litteram* infrastructure for urban sustainability crossing the whole of Yerevan, the relationship between natural and architectural heritage was central in this experiment. The problem assessment, scenario projection, previewing, and informational conceptualization took on a fundamental significance, going even beyond the green heritage conservation/restoration project, the identification of landscape viewpoints, or the creation of comfort areas.

The problematization/contextualization of the green heritage in a global/local sense becomes a fundamental activity for a "project of the project"; they are essential to maintain and enhance the reproducibility and regeneration capacities of the soil, water, air, and their biocenosis. The *Circular Garden* can become a strategic ecological infrastructure system with which to care for the existing green heritage, to encourage its regeneration through ordinary and eventually extraordinary maintenance actions, to reintegrate the floral herbs, trees, and shrub subsystems. Thus, it is a matter of reactivating the performativity and motility of natural environmental systems as the main vectors for the preservation of natural physical-biological processes, the cyclicities of water, air, and carbon flows that ensure the vitality, functionality, and basic ecosystem services for the city[11].

Foresight abilities are central to directing design choices in an enabling sense. According to the World Health Organization's bio-psycho-social paradigm of inclusive and resilient sustainability, systems of environmental factors (e.g., natural resources, buildings, cities, infrastructure, services, and products) are the determinants of people's psycho-physical well-being and their degrees of participation. *Circular Garden* green assets can therefore also enable new sustainable practices and behaviours in city inhabitants[12].

People can develop new sensitivities, habits, and co-design processes (empowerment) to regenerate Nature in the city as a common good. Visioning abilities thus bring into play ways of producing, using, transforming, and economically managing urban green spaces to generate better liveable conditions for individuals and communities.

Informational capabilities are essential to design any intervention on the urban natural heritage. The informational content of the project will have to confront synergistically with the natural performative capacities and the operational-transformative abilities of users. It is necessary to restore the relativities between quantitative design data, contextual qualitative factors, and the quality of healthy and comfortable natural urban physical space. Also in the *Circular Garden*, the concept of capability thus tends to rebuild a system of multiple connections between space, time, energy, and settlements, seeking the degrees of coherence and design content to respond to the maintenance and evolution of cyclicality, relationships, dependencies, circuits, subsidiarity of the city's natural and man-made artefacts.

In this sense, it was possible to rethink the *Circular Garden* not as a collection of quality concentrations. The romantic yet modern dimension of urban natural space made up of parts, point emergencies, or zones has

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[11] About the central rule of *Circular Garden* as physical-biological ecosystemic asset, it is also interesting the historical analysis proposed in T. Amiryan (Ed.), *Getar. Memory of a River. Cultural and Social Narratives Laboratory*, Yerevan, 2023.

[12] The green heritage is included from the World Health Organization in the list of natural environmental factors with enabling capabilities to determine the well-being of people. Cfr. World Health Organization, *ICF/International Classification of Functioning Disability and Health.* Erickson, Geneve, 2006; World Health Organization, *Health Promotion Glossary of Terms*, WHO, 2021.

been overcome. Instead, the possibility of re-evaluating the urban natural heritage as a socio-technical-ecological system, characterised by differences in potential, tensions, and positive/negative balances between the various city apparatuses in a diffuse framework of quality, was evaluated. In this new framework, it is not possible to assign absolute priorities to any elements, neither to envisage only conservative actions nor to work exclusively on the new construction, trying to solve problems by isolating them from their context. It is necessary to have a broad vision to consider each individual part of the *Circular Garden* as part of a superordinate system.

In practice, the possibility of implementing a process of recapitalisation of the *Circular Garden* in its entirety, working on the ecological, socio-cultural, and economic components, was outlined. The idea of quality has thus completely transformed into a flexible path that includes forms of reuse, maintenance, renovation, redevelopment, regeneration, restructuring. A process that responds to decisions that can be made only involving users, also including spontaneous ones, by maintaining or replacing pre-existing parts of the system.

Acknowledgment

Thanks to the colleagues of the National University of Architecture and Construction of Armenia/Faculty of Architecture, professors David Kertmemjian and Varazdat Hovhannisyan, and to all the participants in the experimental workshop "The urban space between public and private dimensions as a technological-environmental boundary system".

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research is supported with the EU funds Erasmus+ Mobility Agreement.

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