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University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy
Универзитет у Бањој Луци, Архитектонско-грађевинско-геодетски факултет

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Introduction 12(1)

Dear readers,

The Editorial Board of the *AGG+ Journal for Architecture, Civil Engineering, Geodesy and Related Scientific Fields* continuously works to improve the journal's content, clarity, and visibility, as well as its visual identity. Therefore, the journal's website is dynamically changing. One important new practice is the online-first publication of papers. Once the review and production processes are finished, papers are made available online, eliminating the need for authors to wait for the annual issue to be published.

Meanwhile, a second special issue entitled *Earthquake Engineering* is also being prepared and scheduled to be published in the first half of 2025. While you await this collection of scientific research reports, you can read the papers in the regular issue 12 ahead of you. The papers predominantly deal with the dynamic stability of built structures, specifically under the influence of earthquakes and wind. Therefore, issue 12 can be seen as an introduction to the upcoming thematic collection.

The editors hope the readership will find the articles constructive, engaging, scientifically profound, and enjoyable. We welcome contributions worldwide and invite researchers, academics, professionals, educators, and students to submit their research and insights for volume 13.

Editors-In-Chief

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DETERMINATION OF THE RESPONSE SPECTRA OF THE SUPERSTRUCTURE OF LENGTH L=3X63.0 M

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DETERMINATION OF THE RESPONSE SPECTRA OF THE SUPERSTRUCTURE OF LENGTH L=3X63.0 M

ABSTRACT

During a seismic impact, the main emphasis is placed on the damage to bridge piers, which were isolated from the horizontal earthquake detector. Accordingly, when calculating the bridges, the reaction spectra obtained from the horizontal earthquake detector are used both for the piers and for the superstructure. The issue of seismic resistance of bridges is very important, especially for superstructures with long spans. It is necessary to construct dynamic curves of seismic resistance for superstructures of a specific system. The article deals with composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m, on which we performed seven real earthquake records for all three categories of soil using the direct dynamic method and built the reference response spectra. Based on the obtained response spectrum and the methodology provided by different normative documents, the calculation of the selected superstructure was carried out, and the force values were determined. **Discussion:** On the basis of the results obtained with the reference response spectra and the curves given in the normative documentation, graphs were drawn, and composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m of the vertical response spectra was determined.

Key words: *superstructure frequency, period, vertical response spectrum*

1. INTRODUCTION

On the basis of the spectral theory of seismic resistance, the determination of the dynamic response spectra processed in all normative documents, which is based on the results obtained by the calculations of the vertical single-mass cantilever system, does not take into account the very diverse calculation schemes of different constructions. Despite the bridges and all other structures of any system, as well as the system itself, the stiffness and mass difference curves are always unchanged and universal, which, in our opinion, is a very big assumption and is far from reality.

In 2012, New York University professors published an article focusing on the importance of the proper selection of a seismic vertical detector for the superstructure of a bridge [1].

In 2018, Iowa State University professors published an extensive paper in which they pointed out that the vertical component of the three components of an earthquake is partially ignored by the use of mitigation coefficients in the regulations, which ultimately yields results that are inconsistent with reality. The partial disregarding of the vertical component of the earthquake is due to three main reasons: 1) the amplitude of the vertical acceleration of the ground is small compared to the amplitude of the horizontal acceleration; 2) peak values of three-component accelerations are lost in time; 3) buildings are characterized by much higher rigidity in the vertical direction [2].

The first two reasons are fair but not always true: there are different types of earthquakes, especially in the vicinity of 50 km from the epicentre, and the vertical coefficient is larger than the horizontal one [3].

The third reason is an acceptable consideration for industrial and civil buildings because the buildings in the vertical direction have great stiffness, and for them, the horizontal components are really dominant, whereas in bridge construction, the vertical ground accelerations can have a significant impact on the stress-deformed state of bridge structures.

Therefore, it is necessary to determine the coefficients of seismic dynamism for the composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m.

2. METHODOLOGY

Figures Composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m consist of two main beams, longitudinal and transverse connections. A reinforced concrete slab is used in the roadway part, which is connected to the main coils with beams. The clearance of the bridge deck is 11.5 m, of which the width of the lane of the carriageway is 7.5 m, the width of the safety lanes is 2.0 m, the width of the sidewalks is 1.5 m, and therefore the total width of the cross-section of the superstructure is 15.90 m. the thicknesses of the lower and upper belt of the main beam are different in different cross-sections and accordingly the stiffnesses are also different (Fig.1).

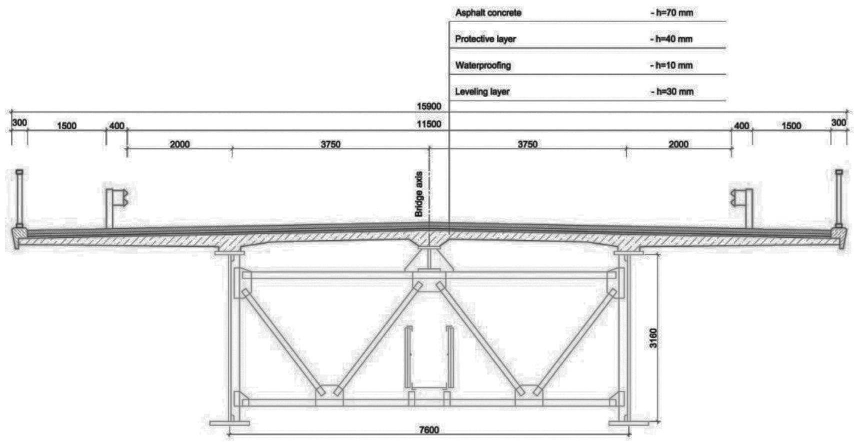

Fig. 1 Cross section of the superstructure with a scheme L=3x63.0 m (Drawing by the authors)

For the superstructure, the frequencies and modal periods for the first three forms of oscillation were determined (Table 1).

Table 1. frequencies and periods of superstructure

L=3x63.0 m			
Oscillation form	Circular frequency rad/s	Frequency 1/s	Period S
1	2	3	4
1	6.26	0.996	1.004
2	11.412	1.816	0.551
3	50.210	7.991	0.125

After fundamental periods and natural frequencies of superstructure were determined for each soil category, seven accelerograms with oscillation periods closest to the fundamental period of a superstructure were selected from the database of accelerograms.

Earthquake peak accelerations have different magnitudes in mutually orthogonal directions. Since the vertical component is dangerous for the superstructure, therefore, such records of vertical oscillation were selected, the oscillation period of which is as close as possible to the fundamental periods of the superstructure.

For this purpose, various accelerograms were selected from the accelerogram, whose main phases were decomposed into harmonics. Harmonics further allows the selection of the specific accelerogram from several accelerograms.

The calculation model of the superstructure was generated using structural analysis and design software MIDAS Civil (Fig. 2). The accelerations of the superstructure were determined using the direct dynamic method. The acceleration spectra were calculated based on the software SeismoSignal 2023.

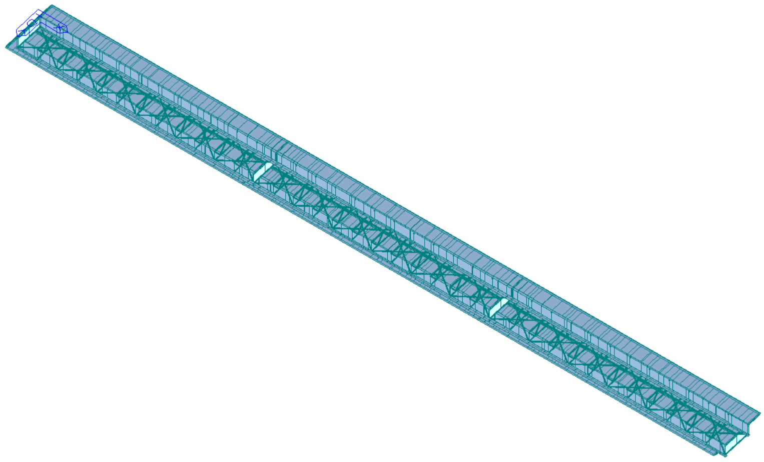

Fig. 2. The reference model of the superstructure of the scheme L=3x63.0 m (Drawing by the authors)

To determine the acceleration spectrum, the real record of the three-component ''Kalamata'' earthquake–accelerogram was used (Fig.3). The vertical component of the accelerogram was separated and normalized in order to exclude the magnitude factor (Fig. 4).

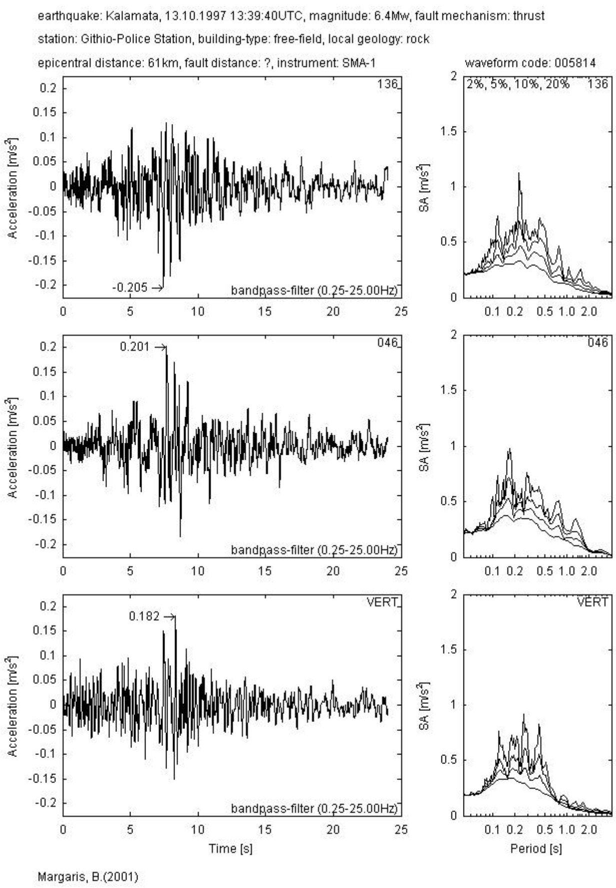

Fig 3. Kalamata earthquake record (code: 005814) (Drawing by Internet-Site for European Strong-Motion DataBase)

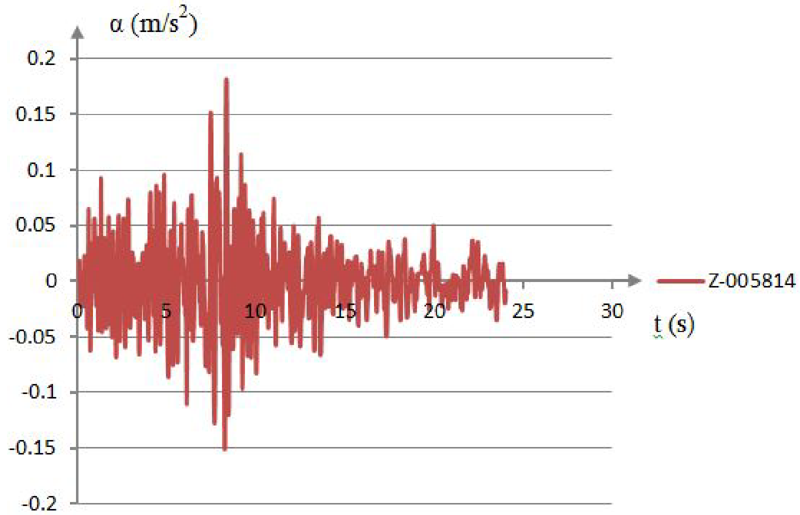

Fig. 4. Vertical accelerogram of the Kalamata earthquake (code: 005814) (Drawing by the authors)

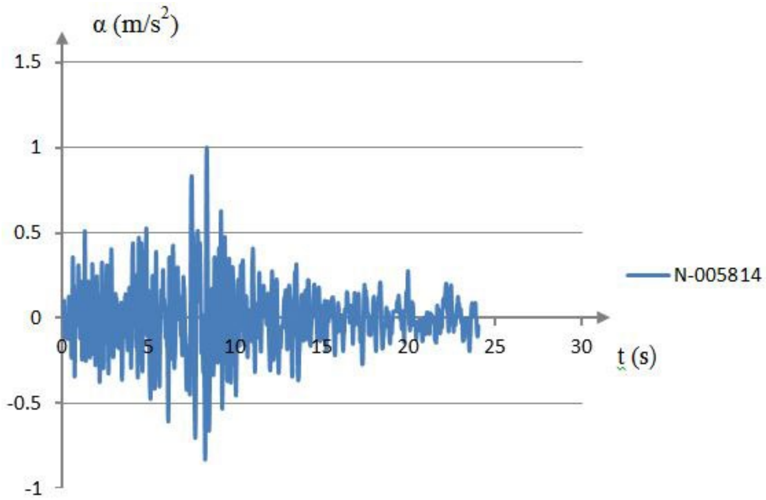

Fig. 5. Vertical normalized accelerogram of the Kalamata earthquake (code: 005814) (Drawing by the authors)

As a result of analysing vertical normalized accelerograms subjected to the 1997 Kalamata 6.4 magnitude earthquake of the superstructure, accelerations were obtained. The results were compared to the normalized accelerations, and it was determined how many times they were increased in the case of the real structure (Fig.6).

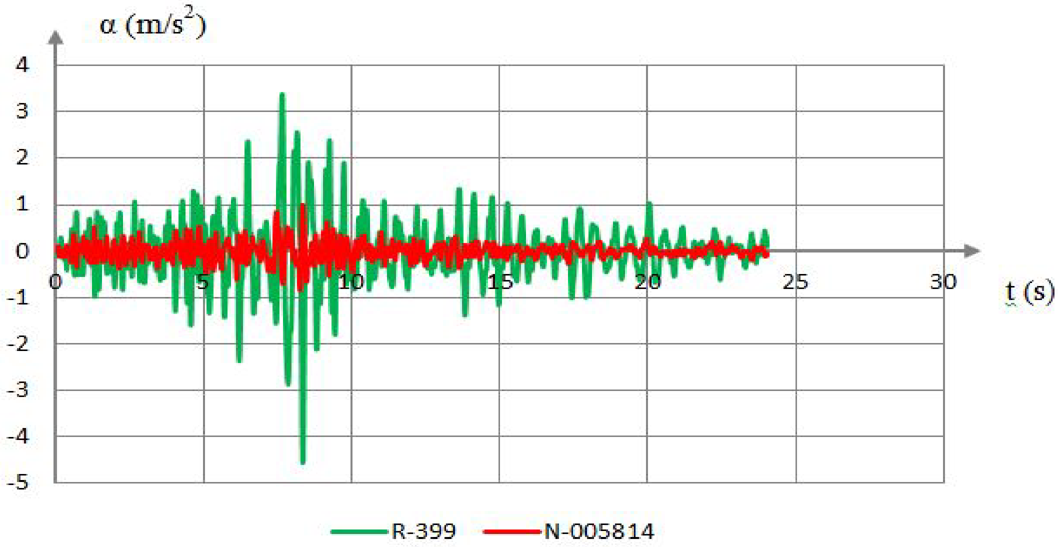

Fig. 6. Vertical normalized accelerogram (code:005814) and response of the superstructure with a scheme L=3x63.0 m under the impact of the Kalamata earthquake (Drawing by the authors)

For this specific case, the maximum acceleration of the response of the superstructure was 4.53 m/s2. Their spectra were constructed accordingly and are presented in Fig. 7.

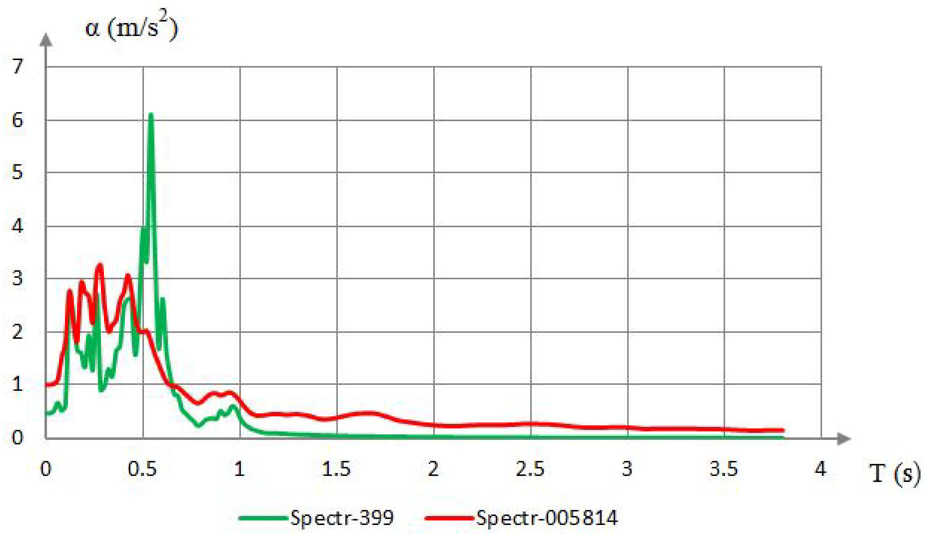

Fig. 7. The vertical normalized spectrum of the Kalamata earthquake (code: 005814) and the response spectrum of the superstructure with a scheme L=3x63.0 m (Drawing by the authors)

The same approach was applied to the rest of the selected accelerograms, which allowed working out the accelerations spectra (Fig.8).

Spectra of accelerations for soils of category I in terms of seismicity are given in Fig. 8, which includes the spectra provided by normative documentation (Geo [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]).

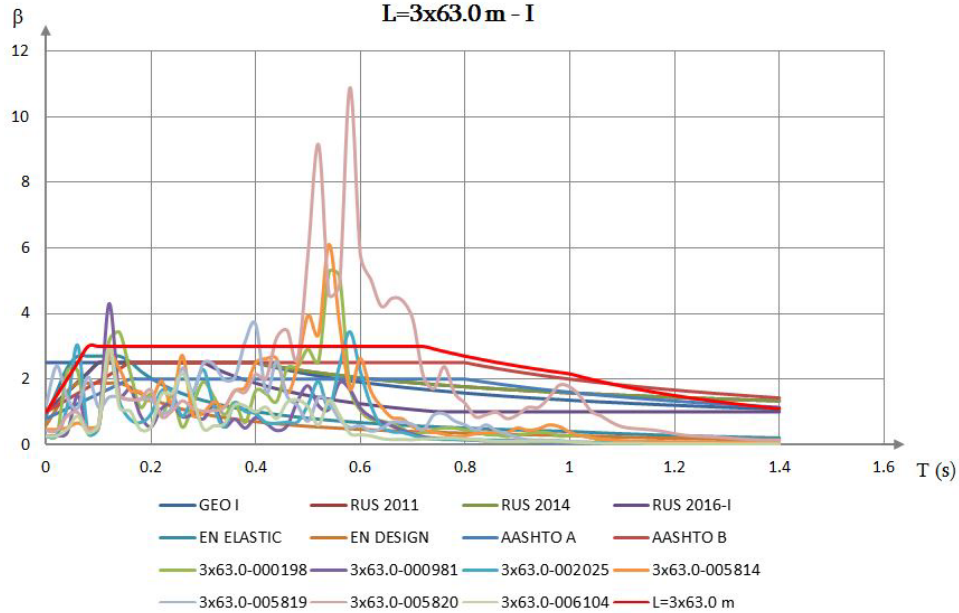

Fig. 8. Response spectra of the superstructure with a scheme L=3x63.0 m for soils of category I (Drawing by the authors)

The same approach was implemented for soil categories II and III during the construction of composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m. Seven accelerograms were selected, and the spectra of accelerations were obtained as results of their impact. They are shown along with the spectra provided by different normative documents (GEO [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]) in Fig. 9 and Fig. 10.

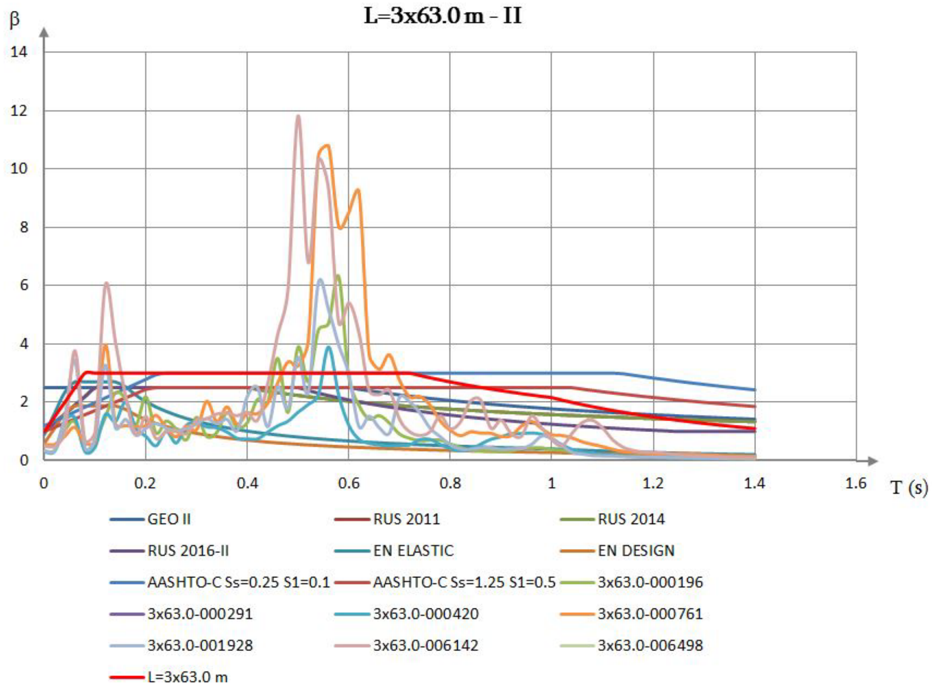

Fig. 9. Response spectra of the superstructure for soils of category II (Drawing by the authors)

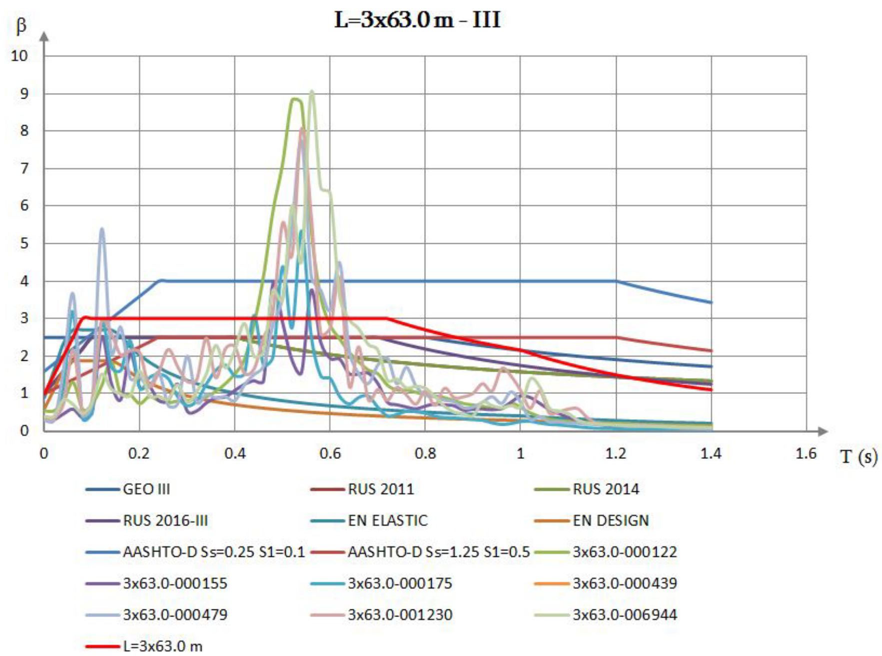

Fig. 10. Response spectra of the superstructure for soils of category III (Drawing by the authors)

The calculation of the selected superstructure was carried out with the spectra obtained by us for the soils of different categories, as well as with the methodology provided by different normative documents (GEO [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]).

3. RESULTS

The vertical component of the seismic action shall be represented by an elastic response spectrum Sve(T), derived using expressions [8]:

$$0 < T < T_B : S_{ve}(T) = a_{vg} \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 3.0 - 1)\right]$$

$$T_B < T < T_C : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3$$

$$T_C < T < T_D : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3.0 \cdot \left[\frac{T_C}{T}\right]$$

$$T_D < T < 4\,s : S_{ve}(T) = a_{vg} \cdot \eta \cdot 3.0 \cdot \left[\frac{T_C \cdot T_D}{T^2}\right] \quad (1)$$

where

$S_{ve}(T)$ – is the vertical elastic response spectrum;

T – is the vibration period of a linear single-degree-of-freedom system;

a_{vg} – is the design ground acceleration;

$T_B = 0.08$ – is the lower limit of the period of the constant spectral acceleration branch;

$T_C = 0.72$ – is the upper limit of the period of the constant spectral acceleration branch;

$T_D = 1.0$ – is the value defining the beginning of the constant displacement response range of the spectrum;

η=1 – is the damping correction factor with a reference value of η=1 for 5% viscous damping.

$$0 < T < 0.08 : S_{ve}(T) = 1 \cdot \left[1 + \frac{T}{0.08} \cdot (1 \cdot 3.0 - 1)\right]$$

$$0.08 < T < 0.72 : S_{ve}(T) = 1 \cdot 1 \cdot 3$$

$$0.72 < T < 1 : S_{ve}(T) = 1 \cdot 1 \cdot 3.0 \cdot \left[\frac{0.72}{T}\right]$$

$$1.0 < T < 4\,s : S_{ve}(T) = 1 \cdot 1 \cdot 3.0 \cdot \left[\frac{0.72 \cdot 1.0}{T^2}\right] \quad (2)$$

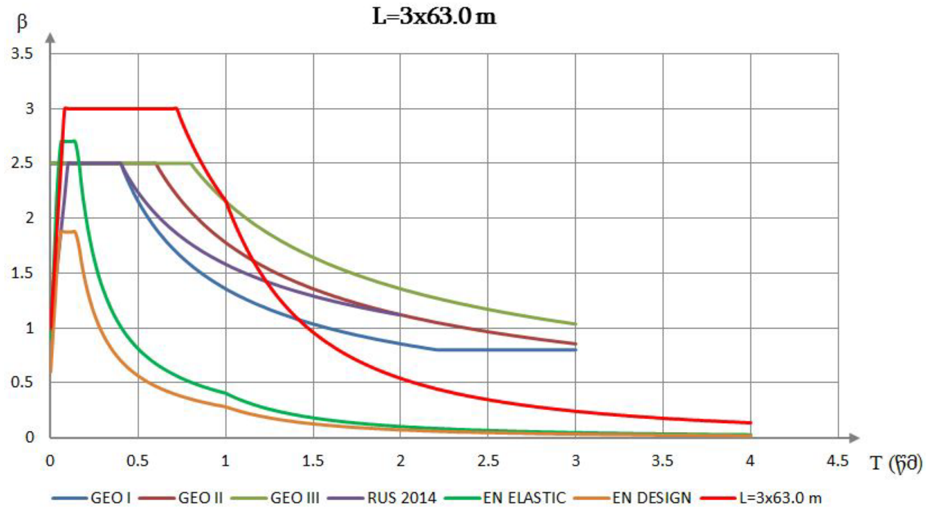

Fig. 11. Vertical response spectra of the superstructure with a scheme L=3x63.0 m (Drawing by the authors)

For the superstructure with a scheme L=3x63.0 m, calculations were made for all three soil categories at different levels. The results of seismic forces are presented in Table 2.

Table2 seismic forces of superstructure with a scheme L=3x63.0 m by different normative documents

Superstructure with a scheme L=3x63.0 m								
N	Name	Static	7 Intensity		8 Intensity		9 Intensity	
		M, t•m	M, t•m	%	M, t•m	%	M, t•m	%
1	L=3x63.0	2552.39	317.21	12.4	634.63	24.9	1271.65	49.8
2	GEO-I		105.94	4.2	254.57	10.0	551.82	21.6
3	GEO-II		131.96	5.2	264.13	10.3	528.49	20.7
4	GEO-III		136.08	5.3	217.86	8.5	408.69	16.0
5	RUS-2011		113.23	4.4	226.68	8.9	453.59	17.8
6	RUS-2014		119.71	4.7	239.65	9.4	479.52	18.8
7	RUS-2016-I		102.84	4.0	205.9	8.1	412.02	16.1
8	RUS-2016-II		165.12	6.5	330.47	12.9	661.39	25.9
9	RUS-2016-III		186.53	7.3	373.27	14.6	746.85	29.3
10	EN ELASTIC		309.47	12.1	619.16	24.3	1238.54	48.5
11	EN DESIGN		171.86	6.7	343.88	13.5	687.98	27.0
12	AASHTO-A		427.29	16.7	855.86	33.5	1715.01	67.2
13	AASHTO-B		534.16	20.9	1070.65	41.9	2144.59	84.0
14	AASHTO-C		884.32	34.6	1712.26	67.1	2952.4	115.7
15	AASHTO-D		1186.46	46.5	2069.35	81.1	3259.03	127.7

The graph presented in Fig. 11 was developed to visualize the results calculated on the basis of various normative documents (GEO [4], SNiP [5] [6] [7], EN [8] [9] and AASHTO [10]).

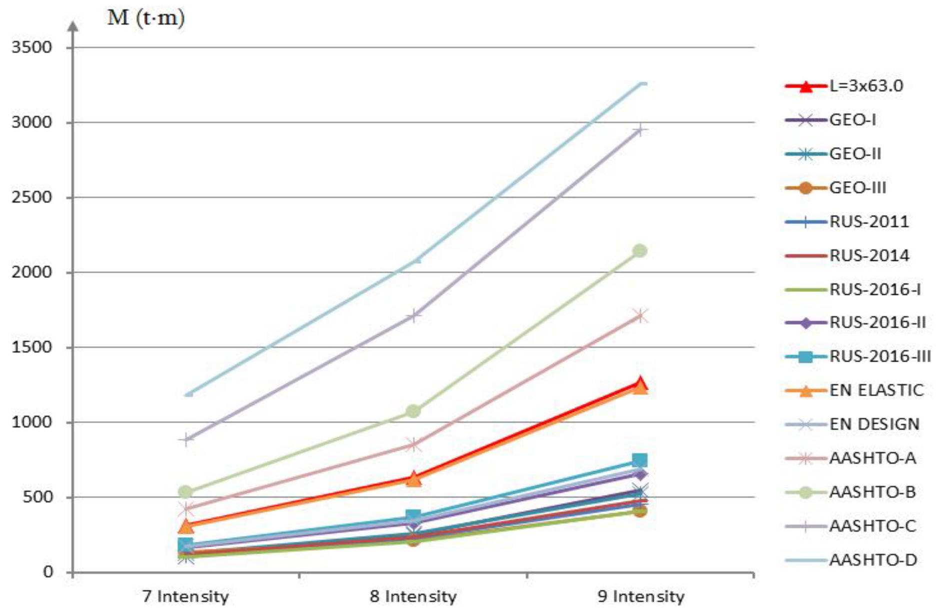

Fig. 11. According to various normative documents and new spectra, the values of the forces of the superstructure with a scheme L=3x63.0 m

Studies have shown that taking into account the first three modes of vibration of the superstructure with a scheme L=3x63.0 m, the magnitudes of the forces determined by the spectrum of the response obtained by the spectra given in the normative documents of (GEO [4] and SNiP [5] [6] [7]. The results also exceed the magnitude of the force received by the spectrum given in the normative documentation of EN [8] [9].

The vertical spectra given in different normative documents (GEO [4], SNiP [5] [6] [7] and AASHTO [10]) take into account different soil categories obtained by transforming the horizontal spectrum. The vertical spectrum is given only in the normative document of EN, and it does not depend on the soil category, which was also confirmed in this research - regardless of different soil categories, the range of the new spectrum obtained on the basis of the response spectra of accelerograms is unchanged. Therefore, it is possible to use one vertical response spectrum for all soil categories.

4. CONCLUSION

The spectra obtained by the impact of accelerograms on the composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m produce significantly higher force values than the spectra obtained without taking into account their own fundamental periods.

As provided in the EN normative document, the following research confirmed that it is possible to use the same vertical response spectrum for all soil categories.

Studies have shown that it is necessary to use wide-area spectra for the long period composite steel and concrete continuous span superstructure with a scheme L=3x63.0 m.

5. ACKNOWLEDGEMENTS

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I graduated from the Georgian Polytechnic Institute with a degree in Railway Engineer-Builder In 1979. From 1979 to 1988, I worked as the head of the track distance at the Tbilisi Metro Rail and Ferns Service. I have been teaching since 1982. I am a Doctor of science (engineering). I have been a professor since 2006, and since 2016 I have been the Head of the Road Department of the Georgian Technical University. Since 2004, I have been engaged in expert work in the railway section. I have published 85 scientific articles, one monograph, 14 textbooks and methodological references.

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I was born on December 17, 1968. In 1993 I graduated from the Georgian Technical University with honours, specializing in bridges and transport tunnels. In the same year, I started working as a laboratory assistant in the Department of Bridges and Tunnels at the same university. I am a Doctor of science (engineering). Over the years I have worked in the same department as a Senior Laboratory Assistant (1994–2000), Seismic Laboratory Manager (2000-2001), Department Assistant (2001–2006), Assistant Professor (2006–2013) and Associate Professor (2013–2017). Since 2017, I have been working as a Professor of Bridging at GTU Road Department. I am the co-author of three inventions. I have published 24 scientific papers.

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ОДРЕЂИВАЊЕ СПЕКТРА ОДЗИВА СУПЕРСТРУКТУРЕ ДУЖИНЕ L=3x63,0 M

САЖЕТАК: Приликом сеизмичког удара, главни нагласак је стављен на оштећења стубова моста који су изоловани од хоризонталног детектора земљотреса. У складу с тим, при прорачуну мостова, реакциони спектри добијени са хоризонталног детектора земљотреса се користе и за стубове и за надградњу. Сеизмичка отпорност мостова је веома важна, посебно за надградње са великим распонима. Неопходно је конструисати динамичке криве сеизмичке отпорности за надградње одређеног система. У раду је обрађена композитна челично-бетонска непрекидна распонска надградња са шемом L=3x63,0 m, на којој смо директном динамичком методом извршили седам реалних земљотреса за све три категорије тла и изградили референтне спектре одзива. На основу добијеног спектра одзива и методологије предвиђене различитим нормативним документима, извршен је прорачун одабране надградње и одређене вриједности сила. Дискусија: На основу добијених резултата са референтним спектрима одзива и кривих датих у нормативној документацији, уцртани су графикони и одређена композитна челична и бетонска непрекидна распонска надградња са шемом L=3x63,0 m вертикалног спектра одзива.

Кључне ријечи: *фреквенција надградње, период, вертикални спектар одзива*

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INTERNAL EXTENSIONS: A CASE FOR THE REASSESSMENT OF THE ARCHITECTURAL PHENOMENON OF GREENHOUSE

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INTERNAL EXTENSIONS: A CASE FOR THE REASSESSMENT OF THE ARCHITECTURAL PHENOMENON OF GREENHOUSE

ABSTRACT

Glasshouses, greenhouses, conservatories and orangeries – all types of buildings intended specifically for plant cultivation – represent a relatively recent addition to the histories and repertoires of horticulture, agriculture and architecture. During approximately three centuries of their notable existence, these structures managed to not only enable the growth of exotic plants removed far from their natural range but also to form a particular genre of architecture, which developed through different phases, from feeble experiment through high exclusivity to near irrelevance – and back into new paradigms of vegetation-culture-architecture relationship. Starting not only from historical/contemporary examples but also from the general promise of enclosed ecologies, this paper aims both to analyse the phenomenon of greenhouse, as well as to explore parameters and options for its further expansion along conceptual and design-oriented lines.

Keywords: *greenhouse, glasshouse, conservatory, nature presentation, programmatic integration*

1. HISTORY AND CONTOUR PROPOSITIONS

Plants create one of the most basic propositions of our experience of space. Additionally, vegetation – or “nature” as it is often simplified– represents the most basic context for architecture. Exceptions would amount only to climatic zones of extreme aridity, salinity or cold. Environments composed predominantly of built forms are also amongst those exceptions but are nonetheless often regarded as incomplete, barren and even inhumane – precisely due to the absence of vegetation. It is perhaps only the sky that “surrounds” architecture more often than plants. However, for most of the architectural history, plants and buildings (especially interiors of building envelopes) very rarely entertained any interconnectedness or close interaction. In classical antiquity, such connections, if built on a grand enough scale (that is, in royal interpretation), even qualified for a “world wonder” [1].

Basic reasons for this lack of interaction can be mostly attributed to (historical) limitations of building materials, building practices and overall economy:

- Built space has, almost permanently, been supremely resource-demanding, financially expensive and mostly in short supply.
- Traditional building materials, either in themselves, their connections and joints, or in appearance and air quality, have, for the most part, been incompatible with humidity that larger plant ensembles demand (but also transpire).
- Transparent and translucent materials – the prerequisite for any cultivation *inside* the envelope – had a very long and gradual history of establishing themselves to be anything more than a darkness-preventing device, let alone a source of adequate illumination for the growth of plants. The cost of these materials was initially prohibitive, but after a certain point, it proved to be a catalyst for the prestige-induced development of the historical greenhouse.

Observed through the lens of the aforementioned (historical) forces, the phenomenon / the idea - of a greenhouse does prove to be a pure progeny of the industrial age and, indeed, might be a distinct illustration of the ways in which industrial production transformed the idea of built space. However, despite these reasons being crucial - and some of the associated problems insurmountable - no less important was also the lack of specific cultural, political and ideological preconditions for the emergence of architectural-horticultural spaces. These preconditions have slowly started to emerge with the early modern period and the rise of two specific socio-cultural phenomena:

- Intense European exploration of the XV and XVI centuries, together with the fact that these (mostly naval) explorations were focused primarily on geographical areas with climatic conditions warmer than those found in Europe. From such locations, early (and later) explorers, often with some members of the crew versed in natural sciences, started to bring numerous seeds and live specimens of exotic plant life.
- Rise of the scientific method and worldview and, within it, the clear emergence of distinct disciplines such as botany. More abstractly, it was the age of Enlightenment, and the principal drive of unimpeded, “pure“ reason at its core, that enabled - conceptually –plants to be decoupled from their original environments and (re)assembled within structures simulate only partial parameters of the original habitat, such as temperature and humidity.

- Much later, new narratives were also called for in the course of greenhouse building revivals of the 1960s/'70s and 2000s. For the seventies, those were narratives of emerging (geo)systemic scientific disciplines, while the most recent impulses relate to either the sustainability of food production or the conservation of biological diversity in an age of possible serious climatic disruptions. Possibly with less of a true invention with regards to the teleology of the greenhouse, this last chapter of the development testifies more to the significance of the legacy, as well as the aesthetic appeal of the previous era of enclosed botanical spaces.

With this expansion and rationalistic structuring of the European worldview achieved, technological advances in iron and glass manufacturing started to shape the classical glasshouse – or 'conservatory' – of the XIX century. Still being very expensive, especially in light of existing glass and window taxations in England, France, and other countries of Western Europe [2], the conservatory became the signalling device for wealth and social status. Initially being used for a wide variety of horticultural and social purposes, the glasshouse quickly became the prime focus for many botanical institutions, which had been in existence for decades and even centuries prior. Large conservatories, glasshouses, and palm houses (etc.) were erected in Kew, Paris, Brussels, Copenhagen, Berlin, Vienna, St. Petersburg, and New York, as well as in aristocratic estates, especially in Britain [3].

Figure 1. Glasshouses at the Royal Botanical Garden Edinburgh [4], displaying an array of periods and elements: on the left side is the Temperate Palm House (Matheson, 1858), with a substantial part of the solid-wall envelope (quite an unusual trait for the time, save for the orangeries of the previous era) and clearstory central nave for the tallest of species. This building is also the highest XIX-century conservatory in Britain [4]. To the rear is the octagonal Tropical Palm House (unknown architect, 1834). The right side of the photograph reveals the Front Range (main glasshouse range, architects A. Pandreigh and G. Pearce, 1960) with its hi-tech structural exoskeleton. Photo: Andrew Bowden, CC BY-SA 2.0 Deed license.

However, what seemed like a dawning of the evolution of the new architectural type (and even field) – coinciding precisely with the spirit and industrial capabilities of the time – proved to be its short and almost only true peak. It lasted only several decades, approximately from the 1830s to 1880s, and was perfectly exemplified by Joseph Paxton's non-horticultural edifice of 1851, where it promised both the new idea of space (and space boundaries) as well as the technological might of continuous envelope expansion [5]. After nearly extinguishing itself by the end of the nineteenth century, the process left behind buildings in a relatively narrow stylistic range: cast- and wrought-iron girders, assembled for maximum span and embellished in high ornamentation (traditional in appearance but with few precise historical stylistic references) [3].

In this paper, based on and extended upon previously published research [6], we will aim to outline the conceptual boundaries of the phenomenon of horticultural-architectural space in the wide range of its designated programmes. We will explore reasons for the short-lived expansion of the XIX century and the logic (and possible inconsistencies) of the phenomenon's revival in recent decades. Further, we will try to construct the conceptual apparatus for understanding and designing the botanical-architectural space, where we will try to be guided by its history, its general components, recent examples and our own design explorations in the field. More so, we will propose that there is a specific programmatic and aesthetic field in architecture, which is based on (re)presentation of the botanical world. We find compelling reasons to increase clarity in this field since the recent inflation of vegetation-related concepts threatens to unnecessarily and regretfully collapse the "bubble" in a similar fashion to the way it happened at the end of the XIX century.

2. METHODOLOGY

The methodological approach has two aims in mind: First, to clarify the wider scope of the (historical) phenomenon of greenhouses, and second, to propose possible directions for design work in the field of enclosed ecologies and botanical collections. Clarification of the scope invites, first and foremost, a typological approach, especially in light of the wide diversity of forms and the different historical types that emerged throughout the development of the greenhouse—such as the orangery—besides the tracing of historical lines and the construction of historical narratives. Thus, we will construct two basic typologies: one stemming from the *programme* and the other from the *form* of the greenhouse. The form itself will be actually studied through the properties of the envelope, which in this kind of building bears disproportionately large significance in both aesthetic and technical sense.

The second part of the methodological procedure, being centred on design possibilities rather than on historical facts alone, proposes (in a substantially more open and free manner) some of the possible key design approaches. It does so by extrapolating upon the *omissions* recognised within the history of the conservatory: which general approaches were not there, which trends were not fully explored, what are unrecognised contemporary tropes, etc. However, any of the proposed directions would still be in conjunction with the core elements of the foundational typology, either in the programme or in the envelope.

3. PROGRAMMATIC TYPOLOGIES

Great botanical conservatories[1], as well as their small, private offshoots, are far from being the only – or even representative – forms of plants grown in enclosures. The broadest

[1] Note on terminology: "conservatory", "greenhouse" and "glasshouse" can often be used interchangeably, except when the applied materials dictate otherwise. "Glasshouse" is obviously inappropriate when glass is substituted with other translucent material. "Greenhouse" is the most general term, though it has its

typology, according to purpose, might be summed up through four broadest designations: general gardening, agriculture, special purposes and botany.

3.1. GENERAL GARDENING

These often combine several purposes but also remain present in many other types since interest in the practices of gardening and resulting ambientes are hardly ever absent from precisely designated botanical spaces. Also, it is in the (historical) nature of greenhouses – and, as we will argue later, perhaps regretfully so – to be overly universal and multifunctional in its spatial arrangement. Thus, many of them acquired their form from one intended use and transferred to another, even though some disadvantages were obvious and hardly ever resolvable. For example, the Nash Conservatory (arch. Nash 1825, rebuilt and adapted by Wyatville 1836) was originally built precisely to fit the category of "general gardening" as something more than a horticultural pavilion adjacent to Buckingham Palace [7]. Its classical architecture (a modification of the outer envelope of the peripteros) was as equally in focus as the exotic plants that it was intended to house. Due to inappropriate positioning on the northern side of the palace, and thus with insufficient light for plants, it was dismantled and rebuilt in Kew Gardens eleven years after the initial construction. There, it changed its botanical roles several times, with its possibilities limited both due to low height and too much solid envelope. Today, it serves auxiliary purposes [8], similar to many orangeries, which, despite our inclination to cautiously observe progressive linearities, probably at least somewhat represent a technological phase surpassed by the nineteenth-century classical greenhouse of iron and glass. (Orangeries will come again to the forefront later in the text.)

Exceptions, transitions and typological overlappings aside, greenhouses intended as a form of "enclosed garden" do exist as a type in itself, and their large overall range spreads from countless small conservatories (most often private, intended for growing of food, ornamentals and simply for pleasure), up to the royal ensembles built to impress by stature and show of horticultural form and colour, rather than by its botanical collection. A prime historical example of this end of the spectrum is perhaps found in the Royal Greenhouses of Laeken, which is a vast ensemble of different greenhouses on the premises of the court and royal gardens of Belgian monarchs. It was conceived and built during several decades (from the early 1870s to early 1900s), upon the wishes of King Leopold II and through his close collaboration with architect Alphonse Balat (and after Balat's death, with Henri Maquet and Charles-Louis Girault) [9]. It was not built as a structure completely devoted to housing endless collections of plants but as a set of representative spaces in a new architectural medium of transparent structures and materials: the "ideal glass palace", as the correspondence between the Balat and King Leopold suggests [10]. It was, at least in extrapolation and outcome, a collection of several new types of new architecture (including a chapel, the Iron Church), none of which served plants exclusively but integrated them into this new vision.

narrower connotation: small garden structure, often with glass alternatives. Here, interchangeable use is often only due to stylistic requirements of the text.

Figure 2. Interior of the Embarcadère Greenhouse, Royal Greenhouses of Laeken (arch. Alphonse Balat, 1874-1890). Photo: Jean-Pol Grandmont, CC BY-SA 3.0 license.

Historical accounts often mention the origins of controlled environment gardening as being a matter of courts and royal wishes and excesses. According to Pliny the Elder [11], physicians of Emperor Tiberius (ca. 30 AD) proposed to Caesar to eat a certain kind of vegetable (a cucurbite) every day of the year. Imperial gardeners achieved the task by devising carts that were drawn inside buildings by night, drawn outside by day – and on cold days, covered with semi-transparent mineral slates (selenite). Much later, in a different part of the world (but before any exact record of European examples), Korean royalty in 1450s also enjoyed a prolonged growing season of citrus trees housed in structures covered with *hanji* (a specific kind of oiled paper, made from inner bark of paper mulberry, *Broussonetia papyrifera*), heated with ondol (underfloor heating), with substantial thermal mass of several earthen walls [12].

Proper greenhouses and orangeries started to appear in Italy and Western Europe in the XVI and XVII centuries, mostly enticed exactly by gardeners (for citrus and other fruits, as well as for apothecaries) [13].

General gardening – for purposes of enhancing the ambience and character of architectural spaces - but also for the production and use of small amounts of food or flowers – remains today by far the most dominant form of horticultural-architectural space, from modest attached extensions in a residential context, through all kinds of “green” embellishments of commercial enterprises (including housing), up to large public projects for new or revitalised spaces.

3.2. AGRICULTURE

Outside of the scope of gardening and its multilayered interests, bulk production of food did not converge with the greenhouse for a very long time. It can be argued that the demise of glasshouses as architecture coincides with continued improvements in glass and iron/steel manufacturing, which, especially during the last decades of the XIX century, democratised ownership of conservatories, thus decreasing its allure as wealth signalling item [14]. These same improvements brought forth opportunities for the mass production of food, thus removing almost all practical limits to the spread of agricultural enclosed environments. The greenhouse escaped the realm of architecture, first into only specific tasks of agriculture and, later, into becoming a significant force in shaping entire landscapes - like in the Netherlands (where glass as a material of choice still dominates) or south Spain (with polyethylene or other kinds of oil-derived translucent materials). Although now a much more widespread phenomenon, this was also an amplified echo of numerous historical examples of agriculture-driven large-scale built modifications of microclimate (and thus of local landscapes).

Figure 3. Contemporary landscape dominated by agricultural glasshouses: Westland, Netherlands. Photo: Tom Hegen, with permission.

Figure 4. A historical landscape dominated by agricultural controlled environments (heat-retaining walls, some with greenhouses): Montreuil-sous-Bois, suburbs of Paris. Photo: unknown author, public domain.

Figure 5. A historical landscape dominated by agricultural controlled environments (heat-retaining walls): Thomery, Île-de-France. Photo: Google Earth, Maxar Technologies 2023.

The past two decades have seen the reconceptualisation of elements of agricultural greenhouses as particularly useful to architecture, urban planning and sustainable design. High environmental costs of food production and transportation have produced many calls for the reintegration of urban life and agriculture/gardening [14]. New concepts of "urban farms" emerged, either as mono-thematic or overlapping with other architectural programs. Up until now, few have been built and put to (effective) production.

Figure 6. Agrotopia, an agricultural greenhouse with visitor and research facilities atop the agricultural market, Oostnieuwkerksesteenweg Roeselare, Belgium (van Bergen Kolpa Architects & Meta architectuurbureau, 2022). Photo: Filip Dujardin, with permission.

3.3. SPECIAL PURPOSES

During the second part of the XX century, specific qualities of light-admitting controlled environments attracted attention to experiments which surpassed individual disciplines such as botany or horticulture. Drawing both from theories of ecological microcosms [15], earth system science and the perceived need to develop a material and operational basis for outer space colonisation, distinct experiments were established in which broader (systemic) parameters of general climate, energy circulation, biological productivity and human integration were deemed more important for exploration, than researching and presenting individual species [16]. The most notable and the largest of these was the *Biosphere 2*, an air-tight complex of microbiomes (simulations of forests, mangroves, savannas, scrubs, deserts, etc.) under a large greenhouse with complex mechanical support systems. *Biosphere 2* (name suggesting its conceptual successor role for the "biosphere 1" – Earth) was built between 1987 and 1991, and in the early 1990s, this complex hosted a rather theatrical and less-than-ideal semi-scientific mission of several humans who lived inside, breathed inside closed circuits of oxygen and carbon, grew food and purified water for complete two years. It continues to serve a unique role among greenhouses today [17].

Figure 7. Biosphere 2*, a research facility in Oracle, Arizona (architecture Peter Jon Pearce et al., 1987-1991), currently run by the University of Arizona for Earth systems and closed ecological systems research, but initially envisioned by one of its founders, John P. Allen, as a vehicle of establishing ways to both repair the Earth's systems and enable life beyond them [16, 17]. Photo: Philéco 1, CC BY-SA 3.0 licence.*

Light-admitting and heat-retaining enclosed spaces do offer themselves for numerous other tasks, sometimes highly derived and quite innovative. For example, practices of ecological design, originating profusely in the 1970s, greatly emphasised the potentials of the greenhouse in many combinations (for example, animal husbandry with entrapment and use of residual animal heat [18]. Perhaps the most interesting, both technically and culturally, is the use of greenhouses for biological wastewater purification. Pioneered by John Todd, these systems used complex assemblies of many kinds of organisms (fungi, algae, bacteria, protozoa, up to molluscs, fish and higher plants – with plants being visually dominant and spatially most demanding). These would be assembled in purification sequences in order to use up the organic matter in wastewater or bind the inorganic pollutants. A controlled environment envelope would be indispensable for optimal and consistent functioning of such systems. In temperate or cold climates, the envelope would be continuous and translucent, but in the tropics, it would consist mainly of controllable shades [19]. The resulting appearance is that of a multifunctional greenhouse, where plants do dominate in size, but it is not strictly a botanical or horticultural structure, but a biological one in the sense of encompassing many kingdoms of life: plants, fungi, animals, bacteria, etc. It is also ecological in the sense of both spontaneous and purposeful arrangements of organisms into interconnected systems. Finally, it is also technological in the sense of having precise tasks, utilitarian boundaries and strict performance parameters. In addition, it represents an object with a wider cultural mission: to address usual (mis)understandings about water, pollution, the interconnectedness of life, and the vitality of natural systems. Todd's work resulted in the establishment of several smaller (often experimental) wastewater treatment facilities, but it also fundamentally influenced a specific niche in wastewater treatment technology. There, plants and glasshouses are being presented as tools for new urban integrations of these formerly unsightly technological facilities. The cultural significance of plants here is underscored by the fact that in contemporary systems of this kind, the biological treatment of wastewater by the plants and on the plant roots comprises a relatively small percentage of the overall process. The rest of the treatment occurs mostly on structures (meshes and similar) intended to host microbial activity at lower depths in treatment pools, where plant roots do not reach in sufficient quantity. [20]. Thus, while not being indispensable, the plants (and with them, the greenhouses) remain the main trump card of those urban planning solutions in which the (waste) water cycle is accepted again into the city.


Figures 8. and 9. South Pest Wastewater treatment facility (Budapest, 2012, architecture: Organica Water, precise authorship unknown to us): Plants grown in a controlled environment assist in the process of aerobic/oxygenated fixed-film wastewater treatment.). Photo: Ognjen Šukalo

3.4. BOTANY

Botanical conservatory (understood *stricto sensu*) represents only a special purpose greenhouse if judged by predominance of use. Agriculture and general gardening cover most of the space and individual examples. Buildings which are devoted solely to most optimally presenting the widest range of botanical specimens and botanical taxa are comparatively rare. However, in terms of architectural achievements and paradigm framework, both historical and recent, it is botany (and its adjacent life science disciplines) which define the field.

There is a great degree of overlap between the botanical conservatory and the one for general gardening and amenity purposes. Differences are linear rather than discrete, but the main defining parameter probably remains the level – and the whole narrative – of information related to plants and their assemblies. In a somewhat wider perspective, although the aforementioned differences in practical examples might be linear, the conceptual differences between the simple amenity - on one side - and the possibility of referring to the whole kingdom of plants of the world – on the other – stand as quite stark and put botanically oriented concepts ahead of all previously explored programmatic types. It is mostly with this idea of *botanical representation* of the "corners of the world" that we will later propose new readings of a greenhouse as such and of its (new) opportunities.

Figure 10. Botanical garden of Padova (Italy) in XVI century lithograph: the Renaissance proclivity towards "ideal" urban forms meets the concept of a botanical garden as a representation of the world itself [21]. Circular outline, surrounded by water, with an inscribed square, subdivided by cardinal directions. Landscaping/architectural layout is attributed to both Andrea Moroni and Daniele Barbaro [22]. The right middle portion of the lithograph presents one of the earliest graphical depictions and probably one of the earliest European examples of a greenhouse [23]

3.5. PROGRAMMATIC TYPOLOGIES: SUMMARY

The growing of plants in contained environments initially started as a peculiarity of the uppermost social strata, as an exercise in providing for the culinary whims of the wealthy. As such, it has its origins in food production but was simultaneously engaged by the practice and culture of general gardening. This initial line of high-class gardening of edible exotics persisted for a long time (arguably until the arrival of relatively fast transportation of food) but has branched into four main lines:

1) General gardening for pleasure and delight. It was in later centuries democratised to form a wide range: from very large and exclusive (as in the example of Belgian monarchs of the XIX century) all the way down to innumerable small conservatories aimed for aesthetics, occasional fruit and even attractive winter microclimate for humans.

2) Mass/commercial food production entered the stage fairly late, only at the moment when the prices of materials and industrial capacities matched the enormous scale of agriculture. This scale continued to direct this particular line of development, easily surpassing the level of individual architectural buildings and spreading to whole landscapes instead.

3) The prospects of a growing environment that can be modified and controlled to a significant degree produced several narrowly focused uses of the greenhouse: experiments in outer space colonisation, water purification, etc.

4) Botanical conservatories branched very early, notably in the early modern period, with the rise of the first botanical institutions and apothecaries. However, it was with the European exploration and colonisation that larger plant ensembles were required. Thus, the ever-improving iron and glass manufacturing enabled the rise of one of the most emblematic new types of XIX-century architecture: the classic botanical conservatory.

4. ENVELOPE TYPOLOGIES

In regards to the way architectural-horticultural spaces are conceived and materialised, we propose a relatively simple set of parameters. First, a conservatory is, typically and historically, a rather simple structure – a bubble of sorts – which most often does not allow for complex internal structuring. Although this proposition is something that we might want to question in our conceptual enquiries later, the envelope remains infinitely more consequential than any aspect of internal structuring. Thus, after programming, the second (or it should have been the first) parameter of this typology pertains to the skin that is there either to let the sun in or to keep the heat in the appropriate range. Leaving conceptual and design concerns for later and for a different kind of discussion, we propose an envelope typology that strictly distinguishes between hard elements and those that permit the passage of light:

4.1. TYPE AND DEPLOYMENT OF LIGHT ADMITTING ENVELOPE

4.1.1. Translucent envelope being non-existent

This possibility pertains, for the most part, to the creation of favourable microclimates through the (partial) encirclement of plant-growing space by buildings, free-standing walls, depressions in the ground, etc. It offers relatively little in terms of increasing critical minimal annual temperatures. (For example, cloudy winter days with little solar gains, followed by a clear night sky, can result in temperatures similar to those outside of this microclimate.) [24] Still, there are possibilities for the advancement of growing conditions on the opposing side of the spectrum: developing extremely warm (and dry) conditions for proper fruiting or flowering of certain species (as well as for avoiding certain plant diseases).

Traditional walled growing enclosures (previously illustrated here by historical speciality-crop growing for Parisian markets) are the principal example, but there are examples of combined use of this approach even in the relatively recent large-scale botanical conservatories.

4.1.2. Translucent envelope being auxiliary

Most (older) historical examples revolve around this concept: Tender exotic (or out-of-season) plants do grow outside in favourable weather conditions but remain housed under translucent material in colder weather and/or by night. Initial (large and formal) European solutions for controlled-environment horticulture were orangeries, high-ceiling, high-aperture and multiple-door buildings intended for housing citrus (and other) plants during winter or night. During warmer parts of the year, plants (in pots or other root containers) would be carted outside, often to be formally presented in designated park-like spaces adjacent to the building itself [25]. Similar to the previous category, solar orientation of the buildings and yards would be such as to maximise thermal and light gains. Versailles Orangerie, designed by Luis Jules Hardouin-Mansart and built from 1684 to 1686, represents one of the most prominent examples of this type of building (although being known for its inadequate light, non-ideal northwestern exposure and malfunctioning heating system). Smaller and simpler orangeries of a similar age exist in many other locations, with examples from Kensington (1705, Hawksmoor), Belvedere (Von Hildebrandt, 1714), Kew (1761, Chambers), Kuskowo (Argounov, 1764) and other across Europe and somewhat later North America [25]. Orangeries - in the sense of this typology: buildings whose envelope combines closed and translucent properties - certainly are somewhat of a "historical phase" of a "proper" greenhouse, determined by dictates of technological and material propositions of the age and were "surpassed" with advents of iron frames and cheaper glass. Still, their architecture is - in not just one sense - more substantial and in a safe continuum with other types of architecture, and has been unfortunately abandoned for a more "perfected" version. The last two centuries have failed to provide us with an adequate prominent example. The New Orangery at the Prague Castle (arch. Eva Jiřičná, 1998-2001) fits that category in name only and is, at least by our understanding of this subject, a classical greenhouse.

Figure 10. Orangery at Royal Botanical Gardens Kew (arch. William Chambers, 1761) currently serves as a restaurant. Photo: Benjamin Evans, public domain.

Figure 11: New Orangery, Prague Castle (arch. Eva Jiřičná, 1998-2001): the name is derived from the historical existence of a citrus-growing structure in the place on which this new building was constructed. In the typology presented herein, we maintain this example to be mainly outside of the (historical) scope of orangeris and, in fact, to represent precisely a greenhouse. Photo: Prazak, CC BY 2.5. license.

4.1.3. Buildings with significant translucent envelope – proper greenhouses

Since establishing itself during the middle two-quarters of the XIX century as the most dominant and prestigious form of controlled-environment-cultivation structure, the (non-agricultural) greenhouse was produced in numerous examples. It appears in wide scopes, both in terms of size (area, volume, height) and in terms of its representative intentions and qualities. This category certainly comprises the central theme of this paper and some of its history, which we have already discussed. Here, we will only note a certain trajectory of change in the nature of the envelope itself through the evolutions that have occurred during the period of renewed interest in the second part of the XX century and onward. At the centre of these changes lie the innovations in the design of a more translucent envelope, fewer construction members inside, larger spans and hemispheric spaces.

Being a child of the “long XIX century” (1789-1914), the conservatory certainly had to wait for tumultuous times of world wars and unstable interbellum to pass, then for more pressing concerns to be managed in the first decades after the Second World War, to arrive yet again at a prolonged period of stability and abundance. It belongs to prosperous times, and the construction of new greenhouses started again around the 1960s. However, a large gap has developed in technology and (quite a bit more) in architectural paradigms since the last time these kinds of buildings were made. New construction systems, new envelopes and new esthetics were to be developed and deployed. Perhaps one of the most illustrative examples of this emerging experimentation and its relation to history is the Front Range of the Edinburgh Botanical Garden.

The brief in the commissioning for this new piece of controlled-environment botanical horticulture was explicit in asking for zero internal structural members and maximum admittance of light. This second request certainly reflects the historical limitations of Edinburgh’s Temperate Palm House, a building with a substantial amount of hard materials in its envelope (see Figure 1), a sort of transitionary form between older orangeries and classic iron-supported greenhouses, but it also speaks well about considerations of local climate of cloudy Scotland [26]. The solution (both by brief author E.E. Kemp and by architects Allan Pandreigh, George Pearce and John Johnson) was found in the concept of "exoskeleton", which might have originated exactly in the universe of greenhouses (in 1853 by Charles Macintosh [26]), but was also completely "of the times" in forming one of the earliest examples of high-tech architecture (see Figure 1).

The second part and the end of the XX century saw large botanical conservatories being constructed in some form of geodesic dome, but it also saw the acceptance of translucent materials other than glass. Most prominent examples include The Climatron (the greenhouse of the Missouri Botanical Gardens, arch. Murphy and Mackey 1960) and, much later, the Eden Project (arch. Grimshaw, 2001). These innovations were partially led by ambitions for both greater light penetration and increased energy efficiency: Replacement of heavy glass asks for fewer and smaller construction members, especially since single-panelled glass remains unacceptably inefficient at conserving heat, while multiple-panelled glass elements would add even more to the weight. Advancements can be considerable, such as in the Eden Project, where the main hexagonal elements span 11 meters due to the lightness of ETFE-insulated „pillows" and with proportionally very thin and scarce structural members [27]. However, new and prominent glass envelopes are still being constructed. Remaining issues with the thermal properties of glass are addressed either by the adequate placement of other elements of the envelope (see further: The Great Glass House by Foster and Partners) or by substantially less need for heat conservation (subtropical climate of Singapore's Garden by the Bay, Grant Associates et al., 2006-2012).

Figure 12: The Eden Project, Cornwall, UK (arch. Nicolas Grimshaw, 2001), the largest public/botanical greenhouse in the world. The envelope is comprised of a hexagonal-triangular tubular steel structure covered with inflated panels made of ETFE (ethyltetrafluoroethylene). Photo: Jürgen Matern, Creative Commons license BY-SA 2.5.

4.2. TYPE AND DEPLOYMENT OF NON-TRANSLUCENT ENVELOPE

Besides being important from the point of view of architectural composition, solid (and especially high mass) materials represent the valuable repository of heat, often gained in large quantities on clear days. This thermal mass enables moderation of temperature extremes – which might have been an uncommon concern of the XIX century classical conservatories, unheeding of the energy use at the time.

4.2.1. None – ground being the only hard material besides the skeleton

It is worth noting that the relationship between the ground and the upper translucent envelope can vary, from the ground being flat through constructing dug-ins on slopes (properly oriented, as in the classic passive solar design of the 1970s) to the construction of greenhouses in depression. For example, Nicolas Grimshaw's Eden Project is constructed on top of an abandoned kaolin surface mine, while Norman Foster's design for Great Glasshouse of the National Botanic Garden of Wales (2000) creates intentional earth banks on the lower (especially northern) parts of the greenhouse.

Figure 13: The Great Glasshouse at the National Botanic Garden of Wales (arch. Foster and Partners, 1995-2000). Besides being surrounded by embankment as a whole, the building has several additional indentations across the section in order to provide opportunities for heat capture and microclimate formation. Photo: Col Ford and Natasha de Vere, CC BY 2.0 Deed license.

Figure 14: Muttart Conservatory in Edmonton, Alberta, Canada (1976, arch. Peter Hemingway). Excavated mounds provide both micro-climatic stabilisation and reduced energy use, as well as a finer relationship with the landscape. The translucent envelope efficiently shrinks into only four high points and almost minimal surface area. The ensemble significantly expands on entrenched notions of a greenhouse. Photo: WinterE229 Winterforce media, public domain.

4.2.2. Hard materials being integrated into the envelope

As a type, classic orangeries provide the most illustrative range of this integration: from solid materials dominating and forming inconspicuous (non-horticulture-related) architecture to roofs and other parts of the envelope dissolving into transparent glass domes. An important design consideration here becomes the ratio of thermal protection (provided by mass) to light penetration (provided, of course, by translucent materials)[24]. The aforementioned orangeries – the more enclosed ones - could do away with maximum light penetration due to the seasonal nature of their operation. Most of their plants were not tropical and thus had some form of dormant season, which, when acclimatised to temperate climate conditions, could be spent in less than ideally lit buildings.

Figures 15. and 16. (Half)greenhouse, Banja Luka, Republic of Srpska, Bosnia and Herzegovina (2011-2014, arch. Ognjen Šukalo) during construction of the heat-retaining northern wall and roof structure. Materials: earth, straw, wood, glass. Photo: Ognjen Šukalo.

4.2.3. Greenhouses attached to other buildings

Here, besides architectural composition (both visual and spatial-programmatic), the main subject becomes the thermal and ambient interdependence between the main (hard material) space and the attachment. Unlike attachment, the integration of greenhouse space with that of hard material architecture belongs to a different conceptual domain, and in this paper will be explored in the following sections.

4.3. ENVELOPE TYPOLOGIES: SUMMARY

In a classical sense - and for all practical purposes also today – the conservatory is comprised almost solely of the translucent envelope. However, upon an inspection of the historical development of this architectural phenomenon, it is easy to recognise specific phases with different ratios of the solid and hard envelope, borne out of technical necessities but directed towards very distinct architectural types and modes of operation – like in an example of orangeries. On the other end of the timeline, during the revival of the late XX and early XIX century, some limitations of the all-translucent envelope have been brought forward, while the mass of the non/translucent part was put to greater use, with not just technical but also aesthetical good results. Overall typology, dispersed throughout the historical timeline, consists of two parts: 1) type of light/admitting envelope and 2) type of non-translucent envelope.

Within the first category, there are three main variants/types:

a) Non-existent translucent envelope (growing in open sky microclimates),

b) Translucent envelope being auxiliary (like in an orangery where it admits light on dormant plants),

c) A “proper” greenhouse with a rich history of development in its appearance and structure.

The second category is comprised of two types:

a) Non-existent hard parts - except for the earth

b) Hard parts being integrated into the envelope, both conceptually and in terms of the thermal properties of the building. The main example is the dug-in conservatory, with very prominent examples being built during the last decades of the XX century.

c) Greenhouses attached to other buildings.

5. CONCEPTUAL PARAMETERS AND POSSIBLE DESIGN AVENUES

I think one of the big architectural issues of the future is realizing the real significance of plants in human life. And the connection between plants and buildings can only get closer, I think.

Nicolas Grimshaw [27]

Enclosed – architectural, that is - spaces admitting enough light and providing enough room for not only plants but their whole assemblies to grow, clearly represent an addition to the historical *progress* of architecture. Such improvements - not in the sense of material improvements, but in the sense of paradigm expansion – might be relatively rare throughout the history of architecture. The world of vegetation accepted into the world of *shelter* seems to offer a promise upon which indeed has been acted but whose potentialities have hardly been exhausted.

Based on previously elaborated history and typology, herein we propose a matrix of parameters for the design of greenhouses as fully integrated elements and entities of architecture.

5.1. PROGRAMMATIC INTEGRATION AND SPATIAL DISPERSION

Despite attached greenhouses being an established genre for a considerable time, further integration still remains a fecund possibility – especially in the domain of plant assemblies intended for botanical presentations. Botanical conservatories have historically, almost exclusively, tended to be isolated programmes, spaces and forms (and this includes the attached version). Modernist, as well as more recent attempts, certainly made steps toward further integration, but mostly in some form of a ‘great hall’. A decent example of this approach is found in Sheffield Winter Garden (by Pringle, Richards, Sharratt, 2002), while New York’s Ford Foundation (Roche, Dinkeloo, Kiley, 1968) remains one of the earliest - and arguably one of the most successful - integrations of semi-botanical plant assemblies and large, unifying hall-like spaces in buildings not primarily related to plant-presentation or leisure.

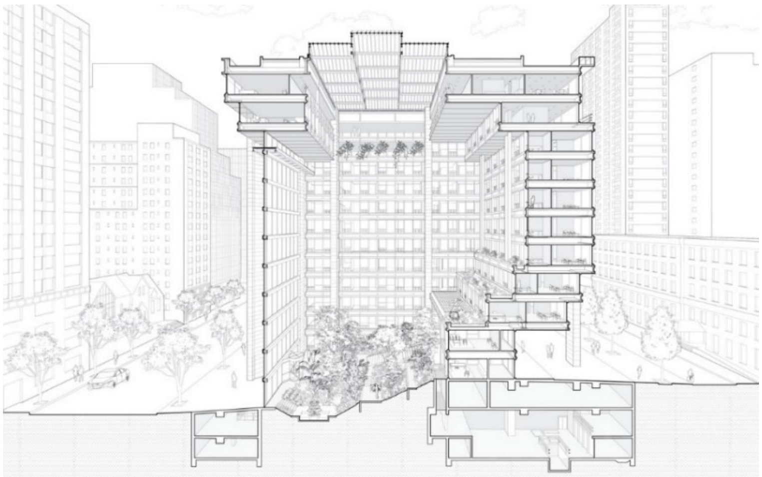
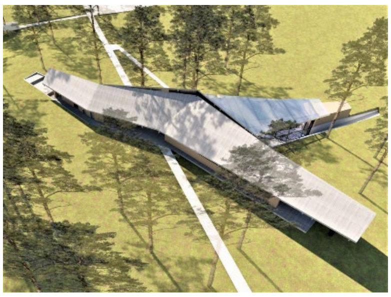


Figure 17: The Ford Foundation, New York (arch. Kevin Roche, const. John Dinkeloo, 1968), perspective section. Source: Lewis, P., Tsurumaki, M., Lewis, D.J.[28], with permission.

Indoor botanical presentations have predominantly tended to form ever more isolated units, which was based on both botanical categorisation/grouping as well as on needs for maintaining proper climatic conditions. These conditions can differ strongly in between, for example, spaces devoted to montane desert plants and those devoted to warm, humid environments. Further development of conservatory concepts emphasized these groupings based more on climate than strictly on botany. For example, the Princess Of Wales Conservatory at Kew (built in 1982-1986 by Arch. Gordon Wilson) contains as many as ten different climatic zones [29]. If this tendency to isolate space strictly along 'scientific' lines is modified, broad opportunities arise to weave botanical narratives with other architectural programs.



Figures 18. And 19.: Concept for the central building of Trapisti Arboretum, Banja Luka (arch. Ognjen Šukalo, Slobodan Peulić, Maja Milić Aleksić, 2020). General spatial disposition (figure 18) shows the glasshouse as an integral part of architectural form; its presentational function is continued into the solid envelope, which is, in turn, being transformed through a thin clearstory roof opening. The perspective section through the glasshouse and entry space (figure 19.) also displays the use of ground indentation for thermal as well as spatial reasons (lowering the building's profile while increasing the useful height). Ilustrations: Slobodan Peulić.

5.2. HEIGHT VS. GROUND

The dimensional range of different plant species is very broad – and it is conceptually relatable to a dimensional-programmatic range of human-built structures. Great conservatories, both contemporary and historical, have mostly responded to these botanical spatial requirements by creating spaces with a balanced spread of ground surface to height – by creating, in the broadest sense, the hemispheric "bubbles". Variations, in XIX century examples, amounted mostly to the incorporation of basilical structural and spatial composition, which allowed for taller plants to stand in the central nave and smaller ones in aisles. Still, geodesic domes of the past several decades contributed to the homogenisation of the vertical-horizontal composition of the greenhouse. We believe it can be argued that this insistence on all-encompassing, even-spreading and homogeneous space greatly contributed to the architecture of conservatories rarely surpassing its ascribed domain of aristocratic folie or scientist's glassed garden. Differences in plant height – and, additionally, in root space requirements – offer a much more diverse and structured palette of elements for architectural composition. Here, the theme of ground should not be overlooked: the rooting space of smaller plants is much more architecturally malleable than the verticality of palms and trees.

Figure 20: Aiming for height: Klimatron *Conservatory of the Alexander Fomin Botanical Gardens in Kiev, Ukraine (1977, authors of architecture unknown to us). Photo: ArtemKo, CC licence 2.5.*

5.3. INTERNAL STRUCTURING

We have already observed that the phenomenon of enclosed horticultural space in almost every case aims not only for optimal penetration of the light through the "skin" of the structure but also eschews any hard-material blockages throughout its interior, like trying, in every instance, to enable light to travel to the centre of the aforementioned "bubble" and the ground. While this is mostly understandable from the point of view of single-programme building, any complex attempt at integration – which would take the greenhouse as its *starting point* – will necessarily have to navigate relationships of light and dark, space and boundaries *inside* of the main envelope.

Figures 21. And 22.: Coupling and "hybridisation" of two types. The greenhouse dominates in the outer envelope but is, in turn, internally structured. Sundby Naturhus, Sweden (2014, Tailor Made Akitekter). The Naturhus (natural house) concept of a house within a greenhouse was first extensively explored in the work of Swedish architect Bengt Warne in the 1960s and 1970s. Photo: Bjorn Wallentinus, Tailor Made Arkitekter and Greenhouse Living (general consultant).

5.4. LANDSCAPING CONTINUATION

There exists a relatively large range of species that might be non-native and not completely acclimatised to a particular (temperate) location of the greenhouse but which does not necessarily require enclosed spaces for these species to survive or even thrive. A microclimatic adjustment often suffices for these plants, and historical examples (for example, peaches in Île-de-France, but also of many botanical rockeries, alpinetums, domestic herb gardens etc.) abound. What perhaps lacks is a more consciously designed *continuum* of a greenhouse and on-the-ground modifications done with form, hard materials, walls and landscaping. Greenhouses need not always stand as sole "objects" imposed upon the surface of the landscape but may be an accent to the larger stretches of intervention.

5.5. OBJECT VS LANDSCAPES

Leaving (relatively) small botanical domain aside, we should pay additional attention to the main field of production of space in regards to enclosed horticulture – that of sprawling landscapes of agricultural greenhouses. Rather than excluding it from the scope of architecture (or viewing it only in terms of the "phenomena" to be researched), these landscapes can be recognised as a legitimate context of any architectural incursion. This seems especially valid in light of intensive (controlled environment) agricultural systems near or within urban centres having ever more importance for providing food for the growing population. It is in these "seas of glass" that solid-material architecture can play an organising role, especially in conjunction with pronounced verticality or visible, out-of-glass greenery.

6. CONCLUSION

The cultivation of plants in controlled environments – in greenhouses, conservatories, and glasshouses - has been a very specific architectural programme since its inception in the XVII or XVIII century. Different demands for light (compared to those related to human indoor use) have at first prevented this architecture from emerging, but later, with advancements in iron and glass production, it went through a few phases to create fully illuminated, completely glazed buildings. These buildings, having their first and highest peak in the XIX century, quickly created its somewhat simple and soon irrelevant genre– despite the ethos of the age being very favourable to glass as an instrument of architecture. A certain revival did appear from the 1960s onwards, but with high correlation to new types of construction (high-tech exoskeletons, geodesic domes, etc.) with still little scrutiny given to the exclusivity of the glass-only envelope and to the detriments of form-based only in geometry. The adoption of the greenhouse in commercial agriculture, with the resulting uncontrolled growth of its use, pushes this type of structure further away from generally accepted realms of architecture and complex design. (Recent explorations of urban agriculture did, however, provide some renewed interest and relevance.)

Starting with the presupposition that the basic tenets end elements of the idea of greenhouse promise substantially more than the history of its implementation has yet managed to provide, we proposed the structure for understanding this idea, as well as what could be, in our analysis, key design landmarks. Understanding begins with covering the basic domains of appropriate use of controlled horticultural environments, where historical dominants of gardening and agriculture are supplemented with special applications, such as constructed ecological systems for research, waste-water treatment, etc. This analysis places the historical flag-bearer – the botanical conservatory – only in the 'special' category but, in doing so, implies different quality and potentiality of narratives of botanical/climatic/ecological assemblies compared to those intended only for general gardening or amenity.

Analysis of essential spatial and material propositions determines the typology according to the nature and potentialities of different types of envelopes, starting from the main one – the ground. Distribution of hard envelopes proves to be undeservedly neglected, thus suggesting the direction for possible programmatic and design improvements. However, surpassing the mere remoulding of the mono-programmatic greenhouse, certain opportunities arise for (as of yet) sparsely explored cross-programme integrations. As the most promising among many, five conceptual parameters of integration are proposed for further expansion of the field:

A) rejection of the paradigm of the single, unified and maximised greenhouse space, or, in other words, suggestion for its dispersion or branching throughout other spaces and programs with which enclosed botanical spaces are being integrated;

B) malleability and expressive potential of markedly vertical plant spaces, along with the horizontal axes and pronounced adaptability of the concept – and spatial distribution – of growing ground.

C) Possibility and even necessity of more complex internal (hard) structuring of buildings which are potentially “hybrid” in nature but still based on the dominance of outer translucent envelope.

D) Continuation of larger strokes of design throughout, primarily landscaping but also potentially through auxiliary and other central buildings – in order for these landscaping elements to create a non-enclosed controlled growing environment and microclimates (while being in aesthetic concert with the glassed ones)

C) Acceptance of sprawling agricultural greenhouse landscapes as legitimate and interesting contexts for interpolations of solid-materials architecture.

In its most developed conceptual form, controlled environments containing exotic plants – organised and presented precisely as such (as ambassadors of biological and planetary riches from far away) – can play a role of secondary context. It would make for a complete additional layer of natural surroundings added to the one existing in the location. It also expands the notion of location, including orientations according not only to near and far surroundings but also to the place and role of buildings and humans in larger processes of the Earth.

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УНУТРАШЊЕ ЕКСТЕНЗИЈЕ: ИНИЦИЈАЛНА ПРЕИСПИТИВАЊА АРХИТЕКТОНСКЕ ФЕНОМЕНОЛОГИЈЕ СТАКЛЕНИКА

САЖЕТАК: Стакленици, ботанички конзерваторијуми и оранжерије – генерално, грађевине намијењене узгајању биљака – представљају релативно скорашњи додатак историјама и репертоарима хортикултуре, пољопривреде и архитектуре. Током приближно три вијека њиховог постојања у иоле развијеном облику, ове грађевине су успјеле, не само да омогуће узгајање егзотичних врста изван њиховог природног ареала, него и да успоставе посебан жанр архитектуре. Овај жанр развијао се кроз неколико различитих фаза: од крхког експеримента, преко високе ексклузивности, до скоро потпуне ирелевантности – уз постепени повратак са маргина помоћу нових парадигми односа између вегетације, културе и архитектуре. Полазећи, не само од историјских и савремених примјера, него и од општег обећања које пружају затворене екологије, овај текст настоји да испита феномен стакленика у тренутном стању, истовремено испитујући параметре и могућности за његов даљи развој у домену (архитектонског) дизајна.

Кључне ријечи: *стакленик, оранжерија, транслуцентност омотача, програмске интеграције.*

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STABILITY CALCULATION OF IRREGULAR STRUCTURES WITH IRREGULAR DISORDER DURING SEISMIC IMPACT

ABSTRACT

From the point of view of modern construction, the damage to reinforced concrete large-panel and frame buildings is especially interesting. The construction of this building is very diverse. Their use has a short history. Therefore, the systematisation of damages and generalisation of results for such buildings is more difficult. Below are some statements sufficiently substantiated with factual material. It is similar to the skeleton of large-panel buildings. However, the resistance of reinforced concrete wall panels is, of course, much higher than the resistance of stone piles. That is why the panels themselves are rarely damaged by earthquakes. Relatively weak points of large-panel buildings are the edges of the panels, the support nodes on the roof panels and other connections. It is in these places that cracks, broken corners and other injuries develop during earthquakes. Three methods of restoration-reconstruction of damaged large-block multi-story buildings are proposed: metal diagonal web member and system-variable rigid in the interior space of the building, using today's terminology with seismic insulators, with the arrangement of additional frames; with reinforced-concrete pylons built over the entire height and perimeter of the building and by arranging loggias in their space; By building pylons along the longitudinal facades of the building and building a floor/floors on top of the building, along with arranging additional frames with seismic insulators if necessary.

Keywords: *Seismic Resistance, Seismic Hazard Zone, SHZ, Buildings, Sustainability, Constructions with Discrete Parameters.*

1. INTRODUCTION

The relevance of the research topic/issue and the novelty of the research in the paper is an attempt to consider several noteworthy or problematic issues identified in the process of performing the mentioned works and to further discuss-determine-specify-solve them. They will be specifically analysed in the appropriate chapters and paragraphs. At the end of this work, we will try to include the solutions and definitions in the list of its novelties, but still, in its introduction, we will single out the terminological problems in the Georgian language that are easily noticeable in almost all similar issues, as well as typical for all areas of our life, including issues of earthquake-resistant construction. These problems are very noticeable among public groups at the level of amateurs of this or that issue, but also, unfortunately, even among professional specialists. Fortunately, today's beneficial changes in many areas of life give us hope that for Georgian professional engineering terminology and various fields of science, proper services will be created for the thorough resolution of similar issues. Moreover, despite always using common sense and logical approaches, we have no claim to the final truth when interpreting and formulating one or another issue below under our point of view.

Under the terms of seismic resistance is determined the ability or capacity of a building structure to withstand dynamic loads caused by earthquakes and strong wind conditions. Loads have its magnitude and direction defined on the local coordinate system acting through the object. To preserve human life, expensive equipment, as well as material and cultural values, it is necessary to ensure seismic resistance of buildings.

For new constructions, seismic resistance of buildings is achieved by using the norms and rules mostly based on the study and analysis of the results and outcomes of earthquakes. For the existing buildings, with a study of each element where visible damage is observed by the user, tenant and/or owner. With that case, everything begins with the examination of the technical condition of the damaged house.

The development of models of seismic hazard zones (SHZ) for a given area consists of two main stages:

- Identification of potentially active areas originating from earthquakes in the study region;
- Determination of their seismic activity level.

The use of such an approach effectively captures the intra-spatial variability of seismicity in the SHZ, the recurrence characteristics of earthquakes, and their epistemic error.

The database includes historical data; the results of field geological studies; all types of geological processes identified in the field (landslides, landslides, rockfalls) and hazard database; Compilation of the base of the catalogue of geological hazards; geological hazards zoning map, where all types of geological processes are depicted; Various thematic maps (geology, exposure of slopes, inclination of slopes as a basis for determining the energy potential of the terrain, etc.).

2. METHODS

The stability of irregular reinforced concrete structures under seismic impact can be calculated using various methods, such as linear and nonlinear static and dynamic analysis.

The method used will depend on the type and level of damage to the structure, as well as the level of seismic hazard [1]. Failures in reinforced concrete structures may include Torsion failure.

Linear static analysis methods, such as the equivalent lateral force method, can be used for structures with small disturbances. Nonlinear static analysis methods, such as Pushover analysis, can be used for structures with moderate to severe disturbances. Nonlinear dynamic analysis methods, such as ageing analysis, can be used for structures with severe disturbances and high seismic hazards. These methods involve simulating the behaviour of the structure under various earthquake ground motions [2]. It is important to note that seismic design codes have different provisions for irregular structures such as UBC97, NEHRP, ASCE7, IBC, IS1893, etc.

The engineer must know the code and the level of disturbance of the building to use the correct method of analysis and design.

2.1. EUROCODE 8-PUSHOVER

Pushover analysis is a method used in earthquake engineering to evaluate the seismic performance of buildings and other structures [3]. It is based on the concept of "stressing" a structure through a series of incremental load-displacement steps, simulating the effects of seismic forces on the structure.

Eurocode 8 is the European standard for earthquake-resistant design of structures, and it contains guidelines for Pushover analysis. Here are some key aspects of Pushover analysis in Eurocode:

- Load patterns: Eurocode 8 recommends several load patterns for Pushover analysis, including unitary, triangular and trapezoidal patterns. These load patterns represent the different types of lateral loads that a building may experience during an earthquake and can be used to evaluate the performance of various structural elements.
- Plastic joint formation: Pushover analysis relies on the formation of plastic joints in structural elements, which represent local failure points of the structure. Eurocode 8 defines the properties of plastic joints, including strength, deformation capacity and energy dissipation capacity.
- Capacity curves: The results of Pushover analysis are usually presented in the form of capacity curves, which show the relationship between the applied load and the corresponding displacement or deformation of the structure. Eurocode 8 gives guidance on how capacity curves should be plotted and interpreted, including how to determine the limit state of the structure and the failure mechanism.
- Nonlinear analysis: Pushover analysis is a nonlinear analysis method that takes into account the nonlinear behaviour of structural members under load. Eurocode 8 guides how to model the nonlinear behaviour of materials and structural elements, including the use of plastic joints and other damage models.
- Verification and validation: Eurocode 8 emphasises the importance of verification and validation in Pushover analysis. This includes checking the input parameters and assumptions used in the analysis and validating the results against experimental data or other established criteria.

Overall, the Pushover analysis in Eurocode 8 is a valuable tool for assessing the seismic performance of buildings and other structures. By simulating the effects of seismic forces and identifying potential failure mechanisms, Pushover analysis can help engineers design more earthquake-resistant structures and improve the safety of buildings and their occupants.

2.2. AIMS AND OBJECTIVES OF THE RESEARCH

The criteria for the accident of damaged buildings have been introduced according to the rate of opening of cracks in the load-bearing structures, which should become a part of the reconstruction methodology for the restoration of the damaged buildings of the existing city housing fund.

A reconstruction-reinforcement-strengthening concept was developed for one specific group of dilapidated residential buildings - for extensions ("buildings" with main and added parts built at different times). The concept of restoration-reconstruction and strengthening-reconstruction for large-block multi-story buildings will be developed so that the group can be strengthened relatively among the mass-series groups (types) of capital buildings.

Three methods of restoration-reconstruction of damaged large-block and frame multi-story buildings will be proposed: in the inner space of the building, metal indirect and system-variable rigid, in today's terminology - seismic isolators, with the arrangement of additional frames; with reinforced-concrete pylons built over the entire height and perimeter of the building and by arranging loggias in their space; By building pylons along the longitudinal facades of the building and building a floor/floors on top of the building, along with arranging additional frames with seismic insulators if necessary.

3. RESULTS

Using the proposed method, increasing the level of seismic safety by changing the construction solution of the building is carried out by rigidly connecting the upper part of the building with a specially built auxiliary structure with certain dynamic characteristics, which takes over a significant part of the impact of inertial forces during an earthquake.

Thus, as the analysis of the results of devastating earthquakes shows, large-panel buildings built under the requirements of normative documents have a fairly high seismic resistance. At the same time, their high level of seismic resistance is ensured by lower costs of materials (for example, in a 16-story large-panel building, compared to other construction system houses of the same height (frame, monolithic, etc.), the cost of metal is reduced by 15-20% per 1 square meter of the total area) and labour costs - by 20-25%).

4. DISCUSSION

The practical value of the research is determined by the implementation of the mentioned scientific innovations in practice and the optimisation of design solutions for the restoration and reconstruction of damaged residential buildings. The effectiveness of the proposed construction system with seismic isolators - simplicity, because the use of seismic isolation in practice allows to reduce the magnitude of the horizontal seismic load on the building by 2-5 times, depending on the seismological conditions and according to the type of building. The realisation of the research results is confirmed by the official document of the implementation of one part of them in practice and the undeniable technical-organisational efficiency of other scientific-practical novelties of the work.

The building calculated and constructed by the normative documents, in which the appropriate increase in price is provided, is intended to absorb only one earthquake or two earthquakes of relatively low intensity, after which the building must either be demolished and a new one built or strengthened by engineering measures.

Both of them are associated with large labour costs, money and time, which will always create big problems for us, especially in housing construction. It was these circumstances that prompted scientists to start searching for new systems of protection against seismic impacts. During the last 20-30 years, several practical methods of seismic isolation systems have been created, which, as mentioned above, are widely used outside our country.

Based on the study of the proposed methods, with given instructions, assumptions and restrictions, the seismic resistance of the building is not improved initially, by increasing the stiffness of its structural joints and elements. That result is achieved by using structural elements, built on its own, separately in the perimeter of the building, with the ability to integrate into the object structure.

The reliability and infallibility of the main results are due to the use of substantiated methods of theoretical and experimental research-analysis, the successful implementation of residential and other types of buildings-reconstruction projects and technological-organisational preparation in the past-current practical processes, as well as the coincidence of the results obtained by other authors. In the cities of the most seismically active countries of the world, there is a significant number of low-rise buildings that do not have sufficient strength reserves in case of a strong earthquake. These buildings were designed and built with norms in which the level of seismic resistance is much lower than the modern seismic resistance norms. In the case of a strong earthquake, these buildings can be seriously damaged, which will cause the death of people and the destruction of material values. A clear example of this is the Turkey-Syria earthquake in 2023, which killed thousands of people.

The problem of strengthening these buildings has great social-economic and historical significance. It is known that many countries have national programs for the reconstruction and strengthening of such buildings.

5. CONCLUSION

The results of research carried out in the paper allow the following conclusions to be made:

- The following observation can be made from the review, the problem of refinement of calculation under the conditions of stability of reinforced concrete structures with irregularity during seismic impact is relevant and is in the stage of active development.
- The transfer of traditional analytical and numerical calculation methods to the considered class of problems faces difficulties related to violations of the geometrical regularity of the structure and the nonlinear nature of the deformation.
- Most of the investigations are devoted to building different models of structural deformation and obtaining differential relationships between loads, deformation components and forces. There is practically no calculation of the stability of reinforced concrete structures with irregularity during seismic impact.

6. ACKNOWLEDGEMENTS

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ПРОРАЧУН СТАБИЛНОСТИ НЕПРАВИЛНИХ КОНСТРУКЦИЈА ХЕТЕРОГЕНОГ СИСТЕМА ТОКОМ ЗЕМЉОТРЕСА

Са становишта савремене градње, оштећења армиранобетонских зграда са великим панелима и рамовима су посебно занимљива. Конструкција ових зграда је веома разнолика, а њихова употреба има релативно кратку историју. Због тога је систематизација оштећења и генерализација резултата за такве зграде тежа. Испод су наведени неки ставови који су довољно поткријепљени чињеницама. Слична је конструкцији великих панелних зграда. Међутим, отпорност армиранобетонских зидних панела је, наравно, много већа од отпорности зидова од камена. Зато су сами панели ријетко оштећени земљотресима. Релативно слабе тачке великих панелних зграда су ивице панела, тачке ослонца на кровним панелима и друге спојнице. Управо на тим мјестима долази до појаве пукотина, ломљења спојева и других оштећења током земљотреса. Предложене су три методе за рестаурацију-реконструкцију оштећених вишеспратних зграда са великим блоковима: метални дијагонални затезни елементи и систем-промјенљива крутост у унутрашњем простору зграде, користећи данашњу терминологију са сеизмичким изолаторима, уз постављање додатних рамова; са армиранобетонским стубовима изграђеним дуж цијеле висине и обима зграде и постављањем лођа у њиховом простору; постављањем пилона дуж уздужних фасада зграде и изградњом спрата/спратова изнад зграде, уз постављање додатних рамова са сеизмичким изолаторима по потреби.

Кључне ријечи: *сеизмичка отпорност, зона сеизмичке опасности, ЗСО, зграде, одрживост, конструкције са дискретним параметрима*

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DYNAMIC COMFORT CONSIDERATIONS IN THE DESIGN OF HIGH-RISE BUILDINGS

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DYNAMIC COMFORT CONSIDERATIONS IN THE DESIGN OF HIGH-RISE BUILDINGS

ABSTRACT

The following paper provides research analysis on the influence of wind on a building, considering the regional and local climate conditions, to improve dynamic stability and reduce wind disruption effects on high-rise reinforced concrete buildings. The main aspect of disturbance in living conditions is caused by wind loads on the building. The data is based on structural analysis, generated by the “Lira CAD 2013” software, for a construction project of a 19-story residential building, completed in Georgia’s capital Tbilisi, 58 Kavtaradze St., in accordance with the given necessary requirements and restrictions by general terms and conditions of the Georgian state law. Computer aided modeling provides the ability to simulate and define parameters caused by the wind disruption on an actual site. Calculation process is based on variables specified by state law for each region of the country. Modified accelerations which have been caused by wind in multi-story, high-rise buildings have significantly greater values on upper floors, and reaching the edges of the minimum living comfort criteria. The given study features the estimation for high-rise buildings under various combinations of loads. High-rise buildings have gone under significant restrictions due to use of conventional rigid frames as structural elements in the construction process. That process tends to develop a series of new research and findings for proper architectural forms, which became possible using the new generation of fast digital computing software and hardware.

Key words: *high-rise building, comfort criteria, wind load, dynamic load, wind distribution, long-term load, wind load acceleration*

1. INTRODUCTION

In recent years, the urban landscape has undergone significant changes with the emergence of high-rise, monolithic apartment buildings, which have become emblematic of economic development. These structures, located in central areas, promise a a comfortable living and solutions to various household issues. The construction of such buildings requires a careful balance between energy conservation, ecological concerns, and other critical factors, with a growing emphasis on ecological safety and integration with service systems [1].

International standards advocate for incorporating natural resources and eco-friendly technologies in high-rise building projects. The global trend includes the construction of high-rise, multifunctional complexes in major cities, addressing land scarcity, population growth, and economic demands. The design criteria have evolved to prioritize resident comfort, safety, reliability, and operational efficiency.

The development of high-rise buildings is particularly prominent in megacities, driven by factors such as rising land prices and population growth. Design considerations have shifted from conventional rigid frames to more flexible structural systems, facilitated by advancements in steel and reinforced concrete technology. The emergence of box-like forms has prompted architects to explore new design trends, leveraging fast digital computers for innovative solutions.

The ideal structure for a high-rise building is characterized by simplicity, regularity, and well-defined load paths in its structural elements. Complexity in configuration and geometry is minimized to streamline building behavior and improve calculability. An analysis of international experience suggests that the construction of buildings with 30-50 floors is economically viable. However, in Georgia, technical solutions for such construction are still evolving, with limited practical experience. Challenges arise in coordinating between high-rise building supervision services, city government structures, and stakeholders such as architects, constructors, and ecologists. Addressing these concerns is crucial for ensuring the successful integration of high-rise complexes in the capital, ultimately benefiting city residents.

2. REGULATION FRAMEWORK

High-rise buildings are more significantly affected by wind loads due to their greater flexibility, which must be taken into account. Among the two main dynamic loads (earthquake and wind) affecting buildings, it is necessary to select the larger one. This selection is defined both by the legislation in force in Georgia and by the international and European standards. The dynamic comfort of the building is not calculated due to its small reproducibility. Wind loads are more frequent and more important for high-rise buildings, especially in the case of aerodynamically complex shapes.

Dynamic comfort criteria are given in the norms of other countries and international standards: (SNiP 2.01.07-85*), ISO 10137, the Canadian National Building Code (NBCC), regulations in Japan according to AIJ, EN 1991-1-4. When calculating buildings using Eurocode, wind acceleration is defined in compliance with Annex B.4. That methodology is closer to the international ISO 10137 standard, since the Eurocode does not provide specific recommendations on the limit accelerations of the wind, and therefore it is necessary to use the international standard [2],[3],[4].

The calculation of buildings in the aerodynamic wind tunnel provides the most accurate results. According to the law in force in Georgia, such a test is not required for high-rise buildings; it is required only for bridges in order to take into account the vibration effect.

The Eurocode and the international ISO 10137 standard provide analytics for buildings up to 200 m in height. For taller buildings, an aerodynamic test becomes necessary, as the standard does not provide wind load data at higher elevations. An aerodynamic test is generally recommended for difficult terrain and complex city development. This test not only provides accurate values of wind load, but also determines the accurate acceleration of the top floor of the building. The norms for conducting the aerodynamic wind tunnel tests for buildings are specified in ISO 4354.

3. PRELIMINARY CALCULATIONS

High-rise buildings have structural and technological specifications. Typically, they can be categorized as sections of frame, structure and core. Safe and reliable operation of these structures sometimes requires special engineering solutions. The design of high-rise buildings is a complex process, considering the list of forces and loads that result in diverse planning solutions.

The following research provides solutions for dynamic comfort criteria in high-rise buildings under the influence of wind. Usually, dynamic comfort criteria of a building are not calculated when their occurrence is not frequent. Wind loads are important for high-rise buildings, especially for a geometry of surface with a difficult or complex aerodynamic shape.

Dynamic comfort criteria for high-rise buildings lack universal standards and vary by country. Norms and standards, such as SNiP 2.01.07-85*, ISO 10137, the National Building Code of Canada (NBCC), AIJ guidelines in Japan, and EN 1991-1-4, outline specific mandatory requirements.

Research data provided by specialized institutions properly describe various types of psychophysical changes by individuals residing in high-rise buildings. Air currents above nine floors induce oscillations with a frequency of 3-4 Hz due to structural loads, potentially causing resonance with the human body's vibration and disrupting physiological activity.

According to the Eurocode, wind acceleration follows the methodology outlined in Annex B4, similar to other international standards. However, the Eurocode lacks specific recommendations on maximum wind accelerations and refers to the international standard ISO 10137 for guidance.

The following solution is given as an example of a 19-story building, with a 2-story garage in the basement (Figure 1).

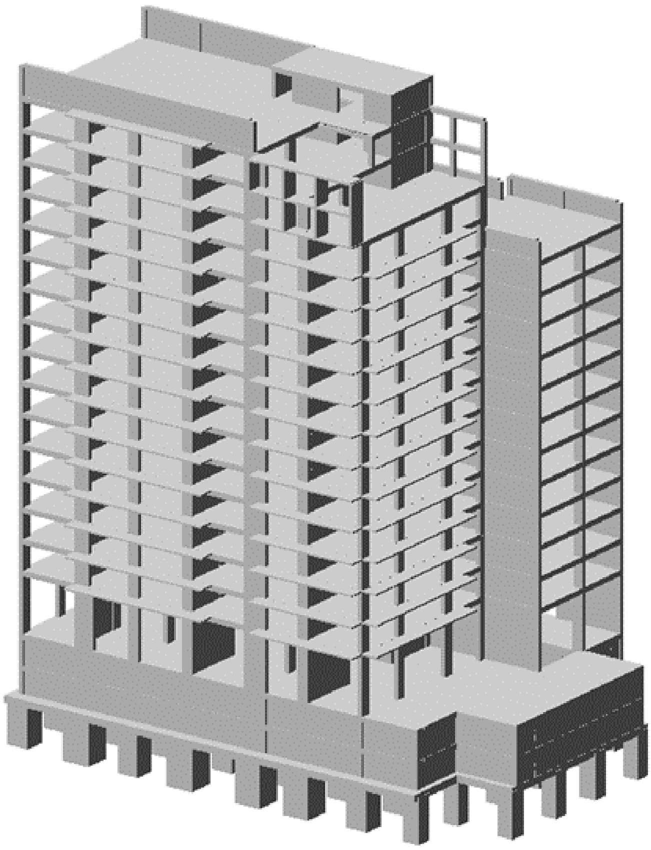

Figure 1. 3D Model of Building (Image Generated by "Lira SAPR 2013" Software)

According to the ground floor plan, the building has maximum dimensions of 44.9X28.1m. The vertical supporting elements are reinforced concrete columns and shells stand as structural members. The roofing structure consists of monolithic slabs and rails. Calculations are based on finite element methods with the "Lira SAPR 2013" software. All variables used in structural calculation are derived from the general terms and conditions defined by the Georgian state law in force.

Seismic load analysis is given for the 2nd ground category, with an acceleration of 0.17g. The initial seismic impact data follows the guidelines from PN 01.01-09 technical document, in accordance with the general terms and conditions of Georgian state law. Specific correlation coefficients are applied for the analysis of static loads. The detailed data is provided in the table below (Table 1) [5].

Table 1. *Wind Direction (W and W/O Safety Coefficient) According to the Terms and Conditions of Georgian State Law for Different Levels of Structure*

Wind Loads				
Building Height	Frontal Side		Vent Side	
	Normative	Accountable	Normative	Accountable
	t/m²	t/m²	t/m²	t/m²
0	0.034	0.048	-0.026	-0.036
6.64	0.037	0.052	-0.028	-0.039
9.96	0.044	0.062	-0.033	-0.046
19.92	0.058	0.081	-0.043	-0.061
39.84	0.075	0.105	-0.056	-0.078
49.8	0.082	0.114	-0.061	-0.085
59.76	0.088	0.124	-0.066	-0.093

The given set of loads is distributed on the columns evenly, corresponding to the area of the exterior surface. It is important to note that, based on research data from specialized institutions, individuals in high-rise buildings experience psychophysical changes due to wind disruption. To be more specific, air currents at higher levels, induced as structural loads above the 9th floor, generate oscillations with a frequency of 3-4 Hz (Table 2).

Table 2. *Frequency Ranges, Intersection to Critical values (Table Generated by "Lira SAPR 2013" Software)*

No.	EIGEN VALUES	FREQUENCIES		PERIODS
1	0.246055	4.06	0.65	1.5452
2	0.201205	4.97	0.79	1.2636
3	0.152244	6.57	1.05	0.9561
4	0.065316	15.31	2.44	0.4102
5	0.059593	16.78	2.67	0.3742
6	0.044384	22.53	3.59	0.2787
7	0.032391	30.87	4.92	0.2034
8	0.029436	33.97	5.41	0.1849
9	0.028755	34.78	5.54	0.1806
10	0.026685	37.47	5.97	0.1676
11	0.025604	39.06	6.22	0.1608
12	0.024253	41.23	6.57	0.1523
13	0.023123	43.25	6.89	0.1452
14	0.022458	44.53	7.09	0.1410
15	0.022316	44.81	7.14	0.1401
16	0.021491	46.53	7.41	0.1350
17	0.019732	50.68	8.07	0.1239
18	0.019334	51.72	8.24	0.1214
19	0.018779	53.25	8.48	0.1179
20	0.018730	53.39	8.50	0.1176
21	0.018329	54.56	8.69	0.1151
22	0.017803	56.17	8.94	0.1118
23	0.017364	57.59	9.17	0.1090
24	0.017049	58.65	9.34	0.1071
25	0.016863	59.30	9.44	0.1059
26	0.016584	60.30	9.60	0.1041
27	0.016524	60.52	9.64	0.1038

If this frequency coincides with the human body's vibration, resonance occurs, inhibiting physiological activity. In such cases, it is necessary to include specialized instructions and practical solutions. Therefore, architects and constructors are actively involved to solve a comfortable living condition.

The impact of loading, including forces from internal loads and structural displacement, must be considered by applying a proper coefficient of reliability. In the given example, the coefficients of reliability above the ground level of the building are provided in the following diagrams (Figure 2, Figure 3).

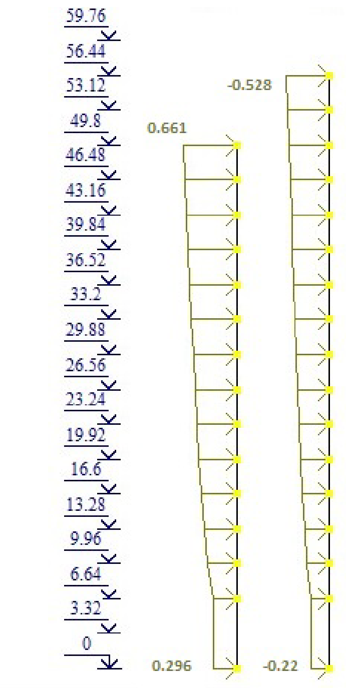

Figure 2. Wind Load for X Direction (Image Generated by "Lira SAPR 2013" Software)

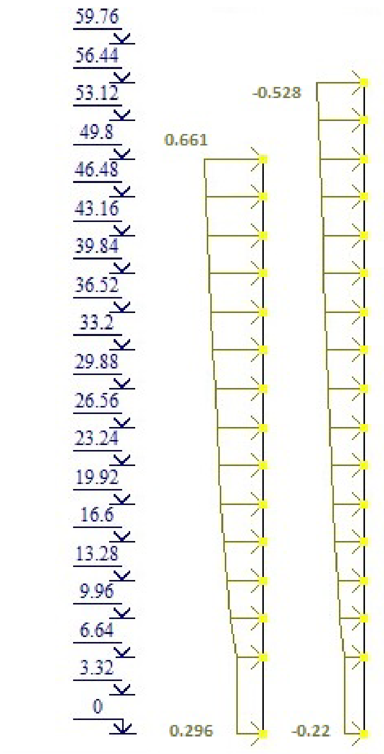

Figure 3. Wind Load for Y Direction (Image Generated by "Lira SAPR 2013" Software)

Depending on building's height and geometry, the wind coefficient has to be estimated using the following data with the finite element method analysis software - Lira SAPR 2013 (Figure 4):

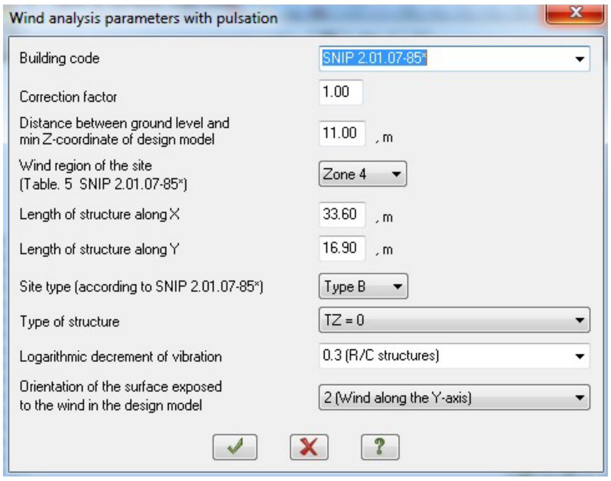

Figure 4. Wind Analysis Parameters for a Specific Zone (Image Generated by "Lira SAPR 2013" Software)

According to the valid standard used for design of structural construction under the Georgian state law (SNiP 2.01.07-85), buildings higher than 40 meters must be analyzed with the wind pulsation coefficient to properly maintain dynamic comfort criteria. This standard also defines the maximum acceleration obtained under wind load for the upper floors - 0.08 m/s^2.

Dynamic load analysis also could be solved with the finite element method using the Lira or Scad software. This allows the wind to be accelerated at the knots for a variety of geometric shapes. The direction of the load is critical to properly determine the vibration values. For the given example, the load caused by the wind condition is estimated with the following equation (1):

$$Wc = 0.5Wp \tag{1}$$

Where: Wp is the design value of the pulsation coefficient.

4. CONCLUSION

The research results show that accelerations caused by wind in multi-story high-rise buildings, especially on the upper floors, are significantly higher, and it is necessary that their values do not exceed the values of minimal comfort criteria. Therefore, it is necessary to consider the given results in the design process.

Aerodynamic testing is highly recommended in the design process of complex geometrical shapes and in the urban environmental development. This also provides accurate values of wind load on the upper levels of the building. Based on the analysis of the given example, it is necessary to determine the comfort living criteria of a high-rise building and refer to the relevant structural engineering guidelines, to avoid deviation from the necessary values for the use of the building.

5. ACKNOWLEDGMENT

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Vladimir Kikadze was born on 03.12.1995. In 2018, he graduated from the Faculty of Construction (Bachelor's Degree) of the Technical University of Georgia with the specialty "Builder-Engineer". In 2020, he graduated from the Faculty of Construction of the Technical University of Georgia (master's degree) with a Master of Engineering in construction, specializing in civil and industrial construction. In 2021, he passed and is studying at the Faculty of Construction of the Technical University of Georgia as a doctoral student. Vladimir Kikadze has been working as an engineer-constructor at "Georgian Technical Group" LLC since 2018.

ДИНАМИЧКА УДОБНОСТ У ПРОЈЕКТОВАЊУ ВИСОКИХ ЗГРАДА

Сажетак: Сљедећи рад даје истраживачке анализе о утицају вјетра на зграду, с обзиром на регионалне и локалне климатске услове, ради побољшања динамичке стабилности и смањења утицаја вјетра на високе армирано-бетонске зграде. Главни аспект нарушавања животних услова је узрокован оптерећењем вјетра на зграду. Подаци су засновани на структурним анализама, генерисаним софтвером „Lira CAD 2013", за пројекат изградње стамбене зграде од 19 спратова, завршен у главном граду Грузије, Тбилисију, улица Кавтарадзе 58, у складу са датим неопходним захтјевима и ограничењима општих одредби и услова државног законодавства Грузије. Компјутерски потпомогнуто моделирање пружа могућност симулације и дефинисања параметара узрокованих сметњама вјетра на стварној локацији. Процес израчунавања је заснован на варијаблама одређеним законодавством за сваки регион земље. Модификована убрзања која су изазвана вјетром у вишеспратницама имају знатно веће вриједности на спратовима, а достижу границе критеријума минималне удобности становања. У датој студији је дата процјена за вишеспратнице под различитим комбинацијама оптерећења. Високе зграде су претрпјеле значајна ограничења због употребе конвенционалних крутих оквира као структурних елемената у процесу изградње. Тај процес тежи да развије серију нових истраживања и открића за одговарајуће архитектонске форме, што је постало могуће коришћењем нове генерације брзог дигиталног рачунарског софтвера и хардвера.

Кључне ријечи: висока зграда, критеријум удобности, оптерећење вјетром, динамичко оптерећење, дистрибуција, дуготрајно оптерећење, убрзање оптерећења вјетром

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MATHEMATICS AND ENTRANCE EXAM RESULTS AS INDICATORS OF ACADEMIC SUCCESS AMONG CIVIL ENGINEERING STUDENTS

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MATHEMATICS AND ENTRANCE EXAM RESULTS AS INDICATORS OF ACADEMIC SUCCESS AMONG CIVIL ENGINEERING STUDENTS

ABSTRACT

It is crucial to select high-quality candidates for college and university enrollment, focusing on preparing them for their future careers in the shortest possible study duration while maintaining a strong graduation rate. The most reliable predictors of academic success (graduation) are observed during candidate testing (entry exams) and within the first year of study.

This paper examines the factors influencing candidate enrollment in the Civil Engineering study program, including performance in mathematics (during the first year of study), the status of enrolled students, and the completion of their studies. It also explores the relationship between the study duration and academic performance in secondary school, the entry exam results, and the ability to predict academic success—graduation.

The goals of the research were to analyze the success achieved during secondary education among SP CE students over the 12-year period, to research the success of students depending on the type of secondary school completed, qualification exam results, study status, passed mathematics courses that students study during the first academic year and to examine the possibility of using more advanced techniques for predicting the completion of studies.

Keywords: *predicting academic success, entry exam, mathematics courses, decision trees, regression analysis*

1. INTRODUCTION

All the countries of Southeast Europe face the problem of low birth rates, which is reflected in the number of secondary school students and their further education (studying). High education institutions implement many activities to interest and select the best candidates for continuing education. Selection of candidates for enrollment is very complex and demands intense and permanent work with potential candidates during their secondary education.

In the first year of the Civil Engineering first cycle study program at the Faculty of Architecture, Civil Engineering, and Geodesy of the University of Banja Luka, students undertake mathematics courses such as Analytical Geometry and Linear Algebra (AGLA), Differential and Integral Calculus 1 (DIC 1), and Differential and Integral Calculus 2 (DIC 2). The majority of students enrolled in this program typically come from gymnasiums and secondary or vocational civil engineering schools. This paper analyzes the significance of the entry (qualifying) exam for admission to the Faculty of Architecture, Civil Engineering, and Geodesy (FACEG), and examines the correlation between entry exam results and success in mathematics courses, as discussed in previous studies [1]-[5]. The impact of passing mathematics courses in forecasting the academic success of students is examined in papers [6]-[9].

This study evaluates three primary factors influencing student enrollment: secondary school performance, entry exam results, and total score. It also examines grades and the timing of mathematics exams (those taken in the first year of study), the status of enrolled students, completion of the first cycle, and the relationship between study duration and success in both secondary school and entry exams.

Advanced analytical techniques, such as decision trees, were employed to predict students' likelihood of graduation. Analysis of mathematical exam performance indicated that the timing of passing these exams (i.e., when the exam was taken and passed) is a more critical predictor of successful completion of the first cycle than the grade achieved in the exam.

Based on the completion and passing of specific mathematical exams during the current study year, the prediction accuracy for successful graduation ranges from 82.1% to 91.5%. Additionally, the prediction for successful graduation among Civil Engineering students is enhanced by generating rules derived from the data.

2. RESEARCH MODELLING

The goals of the research were:

- to research the success achieved during secondary education among SP CE students over the 12-year period,
- to research the success of students depending on the type of secondary school completed, results during the qualification exam, study status, passed mathematics courses that students study during the first academic year, and
- to examine the possibility of using more advanced techniques for predicting the completion of studies. Over a span of 12 years (from 2012, the first enrolment term, to 2023), the Civil Engineering Study Program (SP CE) enrolled or accepted transfers from other faculties, a total of 435 students.

The scoring system assigns a value of 50 points each to the secondary school score and the entry exam, with a minimum passing threshold of 15 points for the mathematics entry exam. As of the beginning of the 2023/24 academic year, there were 311 active students, and 78 students had successfully completed (graduated from) the first cycle of studies.

For the analysis and graphical representation of the data, various statistical tests were applied, including ANOVA (Analysis of variance */ANOVA/* is a statistical *test* used to assess the difference between the means of three or more groups), Independent Samples t-test (compares the means of two independent groups to determine whether the population means are significantly different), χ2 test (compares discrepancies between the expected results and the actual results), Fisher's Exact test (is used to assess the existence of statistically significant differences between the share of categories in two group variables), Kruskal-Wallis test (used to determine if there are statistically significant differences between two or more groups of an independent variable), and Mann-Whitney U test (used to test whether two sample means are equal or not).

To enhance the prediction accuracy for first-cycle completion, regression analysis and classification trees were used, which are among the most commonly applied statistical techniques for generating rules from data [10]-[12]. The analytical-statistical tool IBM SPSS Statistics, version 27, was employed for this purpose [10],[13].

3. RESULTS OF RESEARCH

Figure 1 illustrates the number of high school graduates in the Republic of Srpska from the 2012/13 to the 2021/22 academic year [14].

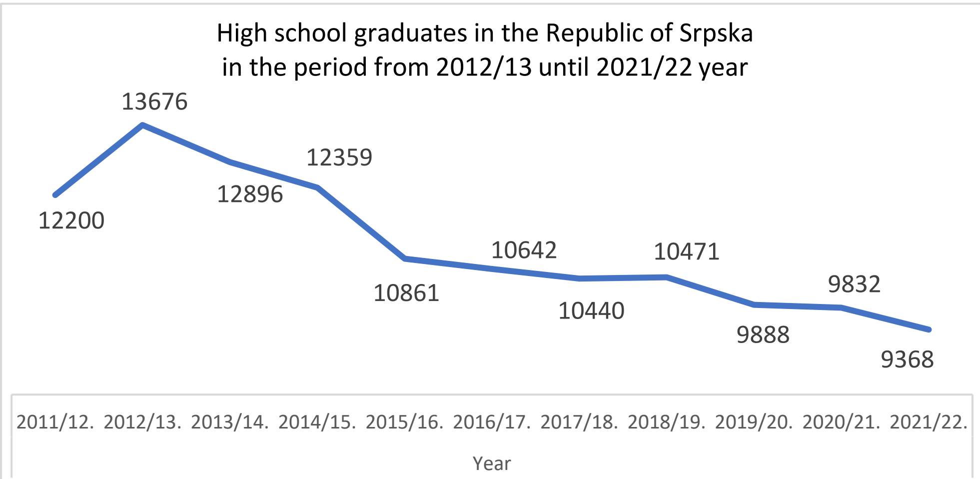

Figure 1. *High school graduates in the Republic of Srpska from the 2012/13 to the 2021/22 year*

The secondary school success scores ranged from 23.1 to 50, with the average score during secondary education being 41.68. Candidates' scores on the entry exam varied between 15 and 50 points, while the average score among enrolled students was 28.17. The total scores, which combined secondary school success and entry exam results, ranged from 38.1 to 100, with the average total score on the entry exam being 69.87.

Figure 2 illustrates the average success rates in secondary school during the entry exam and the total scores of SP CE students over the 12-year period.

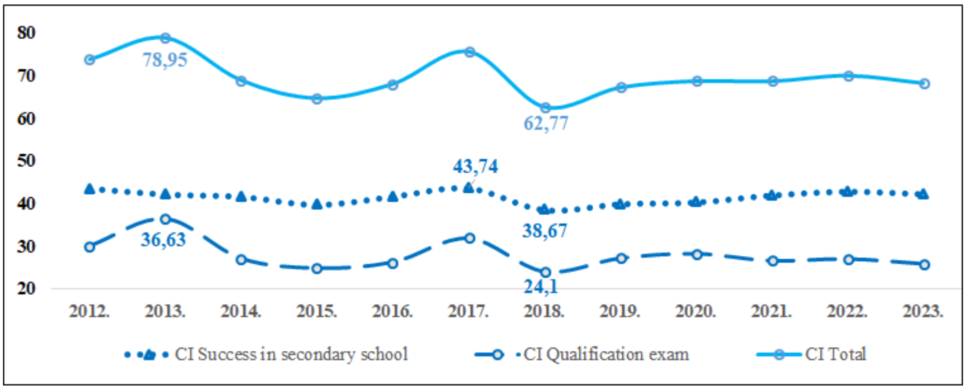

Figure 2. *Average success in secondary school, during the entry exam, and a total score of SP CE students over the 12 years*

Applying the ANOVA test, we found a statistically highly significant difference (p = 0.008) in the success achieved during secondary education among SP CE students over the 12-year period. Further application of the Multiple Comparisons Post Hoc test revealed a statistically significant difference (p = 0.045) in secondary education success between SP CE students enrolled in 2017 and those enrolled in 2018.

A statistically highly significant difference (p = 0.000) was also identified when applying the ANOVA test to the entry exam results of SP CE students over the 12 years. Further analysis using the Multiple Comparisons Post Hoc test showed statistically highly significant differences (p = 0.004; 0.000; 0.004; 0.000; 0.005; 0.000; 0.002 and 0.001) in entry exam success between students enrolled in 2013 and 2014, 2015, 2016, 2018, 2019, 2021, 2022, and 2023, respectively. Additionally, a statistically significant difference (p = 0.019) was observed between students enrolled in 2013 and those enrolled in 2020.

Students' secondary schools were categorized into three groups: Gymnasium, Vocational Civil Engineering Secondary School (Civ. Eng. School), and other secondary schools. By applying the ANOVA test to the data of SP CE enrollees, we identified a highly significant difference in secondary education success (p = 0.000) and a significant difference in entry exam performance (p = 0.022) among the three groups over the 12-year period, based on the type of secondary school completed.

Significant differences are noticeable in the success of candidates during their high school education and the results achieved on the entrance exam, with the best results on the entrance exam being achieved by students in 2013 and 2017.

There are noticeable differences in the success of candidates during secondary school education and the results on the professional exam, and the best results on the professional exam were achieved by students in 2013 and 2017.

The status of students enrolled up to the academic year 2019/20 (those who had the potential to graduate) is detailed in Table 1, showing that 272 students were enrolled by the 2019/20 academic year.

Table 1. *Status of students enrolled by 2019/20.*

Students' status	Secondary schools (groups)			Total
	Gymnasium	Civ. Eng. school	Other secondary schools	
active	56	57	55	168
dropped out	21	31	22	74
no status	4	16	10	30
Total	81	104	87	272

The application of the $\chi 2$ test did not reveal a statistically significant difference ($\chi 2 = 6.513$, $p = 0.164$) in the students' status based on the type of secondary school they completed. However, when applying the ANOVA test, a statistically highly significant difference was found ($p = 0.000$; 0.002) in both secondary education success and entry exam performance among SP CE students in relation to their study status. Further analysis using the Multiple Comparisons Post Hoc test indicated a statistically highly significant difference ($p = 0.000$; 0.002) in secondary education success between active students who dropped out and students without status, respectively.

Additionally, a statistically highly significant difference ($p = 0.003$) was identified in the entry exam performance between students who remained active and those who dropped out.

While investigating the status of students, no statistically significant difference was found concerning the type of high school from which they graduated. However, a highly statistically significant difference was identified in their success in high school education, their performance in the entrance exam, as well as between active students and those who dropped out or are without status.

When researching the status of students, no statistically significant difference was found regarding the type of high school completed. However, a statistically highly significant difference was observed in both high school success and entrance exam success, as well as between active students, students who stopped studying, and those without status.

The mathematics courses passed by students enrolled up to the academic year 2019/20 are detailed in Table 2.

Table 2. *Achieved marks in mathematics courses taken till 2019/20.*

Course	Mark					Mean	Total
	6	7	8	9	10		
AGLA	68	50	36	15	3	7.04	172
DIC 1	65	49	27	15	11	7.15	167
DIC 2	76	31	22	17	10	7.06	156

The period of taking the passed mathematical exams for students enrolled by 2019/20 is shown in Table 3 and Figure 3.

Table 3. The time of taking the math exams in the period until 2019/20.

	Exam passed				Total
	In current year	In next year	After two or more years	Not passed	
AGLA	152 (80.8%)	18 (9.6%)	2 (1.1%)	16 (8.5%)	188
DIC 1	129 (70.1%)	28 (15.2%)	10 (5.5%)	17 (9.2%)	184
DIC 2	51 (30.7%)	63 (38%)	42 (25.3%)	10 (6%)	166

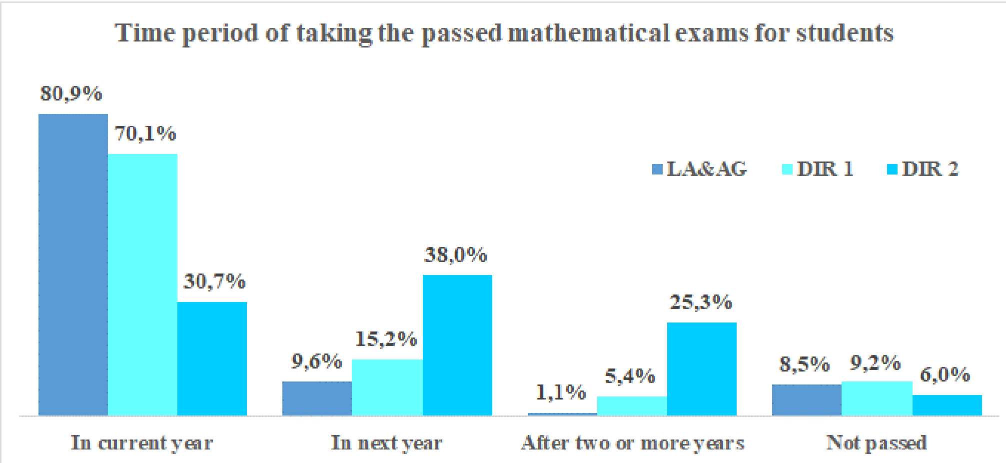

Figure 3. The period of taking the passed mathematical exams for students

Graduates enrolled until 2019/20 in relation to their completed secondary school are shown in Table 4.

Table 4. Graduates enrolled until 2019/20 and completed secondary school

Sec. school /groups/	Graduated		Total
	Yes	No	
Gymnasium	22	34	56
Construction school	31	26	57
Other secondary schools	25	30	55
Total	78	90	168

The χ^2 test was applied, and no statistically significant difference was found ($\chi^2 = 2.621$, $p = 0.270$) in the number of students who graduated versus those who did not, in relation to the type of secondary school they had previously completed.

Table 5 and Figure 4 present the average mathematics grades of both graduates and non-graduates who had enrolled by the academic year 2019/20.

Table 5. *Average mathematics grade of (non)graduates*

Graduated	Secondary school (groups)	AGLA	DIC 1	DIC 2
Yes	Gymnasium	7.50	7.95	7.73
	Civ. Eng. school	7.23	7.32	7.19
	Other secondary schools	7.32	7.44	7.72
	Total	7.33	7.54	7.51
No	Gymnasium	7.04	6.96	7.05
	Civ. Eng. school	6.79	6.47	6.32
	Other secondary schools	6.44	6.75	6.39
	Total	6.75	6.74	6.59

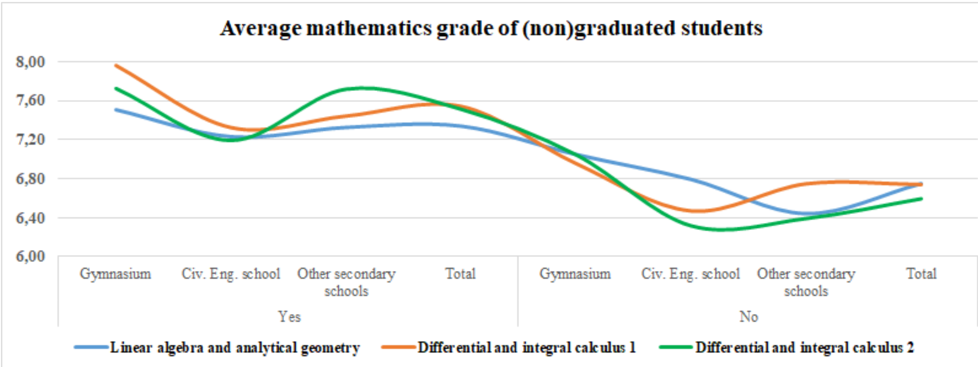

Figure 4. Average mathematics grade of (non)graduates

Table 6 shows the duration of studying (days) for students who completed the first cycle.

Table 6. *Duration of studying (days)*

Secondary school (groups)	N	Min.	Max.	Median	Mean	Std. Dev.
Gymnasium	22	1478	2923	1941.50	2016.14	402.819
Civ. Eng. school	31	1544	3427	2076.00	2190.65	496.071
Other secondary schools	25	1495	2699	1991.00	1992.44	283.030
Total	78	1478	3427	2002.50	2077.90	416.747

We did not detect a statistically significant length of study using the Kruskal Wallis Test ($\chi^2 = 2.368$, $p = 0.306$) for students who graduated depending on their completed high school.

We discovered a statistically highly significant correlation between the negative prefix of the length of studying and success in secondary school ($r = -0.317$) and between the positive prefix of success in secondary schools and the entry exam ($r = 0.356$).

Graduates, depending on the place of their secondary school (group), are shown in Table 7.

Table 7. Graduates, depending on the place of their secondary school (group)

Secondary school (groups)		Graduated: Yes	Graduated: No	p
Gymnasium	Banja Luka	7	9	.897†
	Other cities - municipalities	15	25	
	Total	22	34	
Civ. Eng. school	Banja Luka	29	24	1.000‡
	Other cities - municipalities	2	2	
	Total	31	26	
Other secondary schools	Banja Luka	2	3	1.000‡
	Other cities - municipalities	23	27	
	Total	25	30	
Total	Banja Luka	38	36	.278†
	Other cities - municipalities	40	54	
	Total	78	90	

† χ^2 test with Yates's correction for continuity
‡ Fisher's Exact test

Applying the χ^2 test with Yates's correction for continuity and Fisher's Exact test, we did not detect statistically significant differences in the number of students who (did not) graduate in relation to the previously completed secondary school (groups) and place of secondary school graduation (groups).

In Figure 5, the achieved success in high school (left) and accomplishments during the qualifying exam (right) are shown in relation to the completion of studies (graduation).

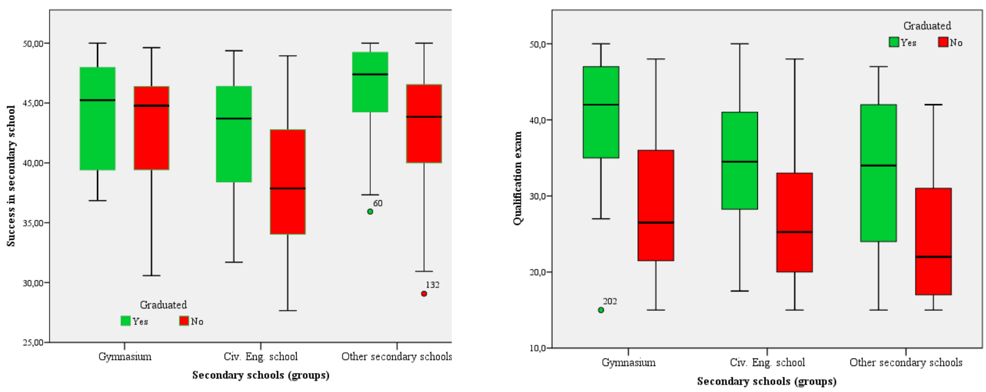

Figure 5. *Achieved success in high school and accomplishments during the qualifying exam.*

Using the Mann-Whitney test, when testing for the (non)completion of studies, a highly statistically significant difference in the achievements of grammar school students during the qualifying exam was found (p = 0.000), as well as in the achievements of students from other schools during high school education (p = 0.007) and during the qualifying exam (p =

0.004). Additionally, a statistically significant difference was observed in the achievements of construction school students during high school education ($p = 0.039$) and during the qualifying exam ($p = 0.011$).

Table 8 shows the duration of studies (in days) for students who completed the first cycle of studies, depending on their performance in mathematics-related courses.

Table 8. *The duration of studies (in days) depending on the completion of mathematics courses.*

		Duration of studies (days)				
		N	Min.	Max.	Median	Mean
AGLA - passed	In the current year	77	1478	3427	1992	2071.3
	In the following year	1	2584	2584	2584	2584
DIC 1 - passed	In the current year	73	1478	3187	1991	2033.6
	In the following year	5	2076	3427	2740	2724
DIC 2 - passed	In the current year	37	1478	2999	1908	1951
	In the following year	34	1544	3187	2045.5	2096.9
	In the next two years	7	2118	3427	2699	2655.3
Total		78	1478	3427	2002.5	2077.9

Using the Mann-Whitney U test, a highly statistically significant difference ($z = -2.795$, $p = 0.005$) was found in the duration of studies (in days) between students who passed the DIC 1 course in the current year and those who passed it in the following year.

Using the Kruskal-Wallis test, a highly statistically significant difference ($\chi2 = 14.115$, $p = 0.001$) in the duration of studies (in days) was also found among students who passed the DIC 2 course in the current year, the following year, or after two or more years.

Additional application of the Mann-Whitney U test revealed:

- No statistically significant difference ($z = -1.888$, $p = 0.059$) in the duration of studies (in days) between students who passed the DIC 2 course in the current year and those who passed it in the following year.
- A highly statistically significant difference ($z = -3.450$, $p = 0.001$) in the duration of studies (in days) between students who passed the DIC 2 course in the current year and those who passed it after two or more years.
- A highly statistically significant difference ($z = -2.790$, $p = 0.005$) in the duration of studies (in days) between students who passed the DIC 2 course in the following year and those who passed it after two or more years.

A highly statistically significant difference in the duration of studies (in days) was found between students who passed the DIC 1 and DIC 2 courses in the current year and those who passed in the following year.

A highly statistically significant difference was found in the duration of studies (in days) between students who passed the courses DIC 1 and DIC 2 in the current year and those who passed them in the following year.

By examining the correlation between passing two or all three mathematics courses studied during the first year, the results indicate that students are more likely to successfully complete their studies if they pass at least two courses within the current year. Alternatively, students can pass at least one course in the current year and the second, or the second and third, in the following year or the year after (Table 9).

Table 9. *Correlation of passing of particular courses and completion of the first cycle (graduation)*

Course(s)	During the current year	Graduated	During the next year	Graduated	After two years or later	Graduated
AGLA	123	101 (82.1%)	26	20 (76.9%)	2	1 (50%)
DIC1	105	93 (88.6%)	31	20 (64.5%)	13	9 (69.2%)
DIC2	47	43 (91.5%)	50	46 (92%)	49	33 (67.3%)
AGLA & DIC1	96	87 (90.6%)	40*	26 (65%)	13**	9 (69.2%)
AGLA & DIC2	47	43 (91.5%)	50*	46 (92%)	49**	33 (67.3%)
DIC1 & DIC2	47	43 (91.5%)	50*	46 (92%)	49**	33 (67.3%)
AGLA, DIC1 & DIC2	47	43 (91.5%)	50*	46 (92%)	49**	33 (67.3%)

* at least one of the courses passed in the following year
** at least one of the courses passed after two years

Additional correlation of monitored variables is possible to find using advanced techniques. As examples, we give the application of the decision trees (Figure 6 and Figure 7).

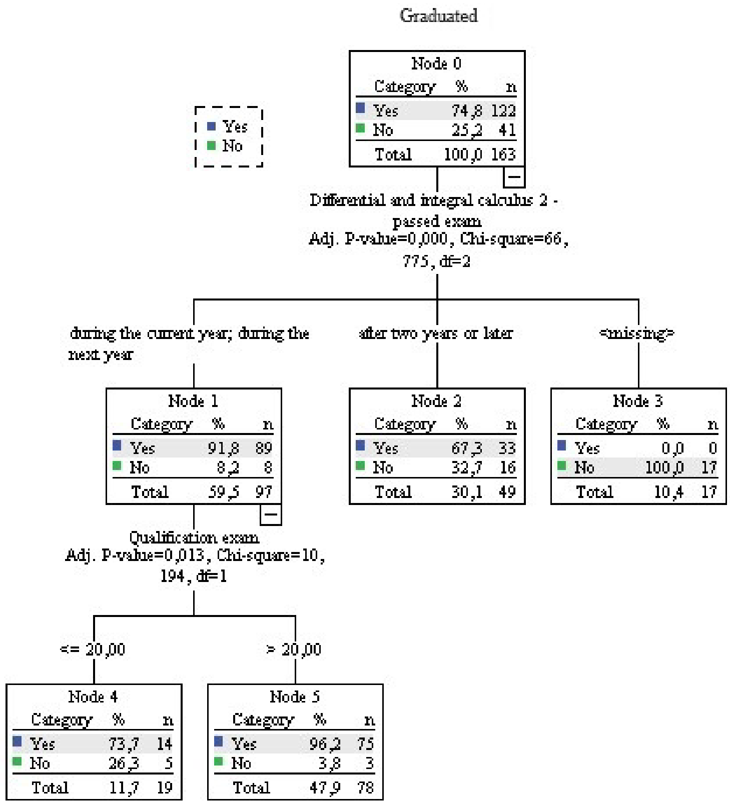

Figure 6. *Example of the decision tree*

Generated rules for three nodes are given as an example:

/ Node 4 */.*

IF (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year") AND (Qualification exam NOT MISSING AND (Qualification exam <= 20))

THEN

Node = 4

Prediction = 1

Probability = 0.736842

/ Node 5 */.*

IF (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year") AND (Qualification exam IS MISSING OR (Qualification exam > 20))

THEN

Node = 5

Prediction = 1

Probability = 0.961538

/ Node 2 */.*

IF (Differential and integral calculus 2 - passed exam = "after two years or later")

THEN

Node = 2

Prediction = 1

Probability = 0.673469

By forcing the variable „Entry exam“, we generated the tree (Figure 6) and rules.

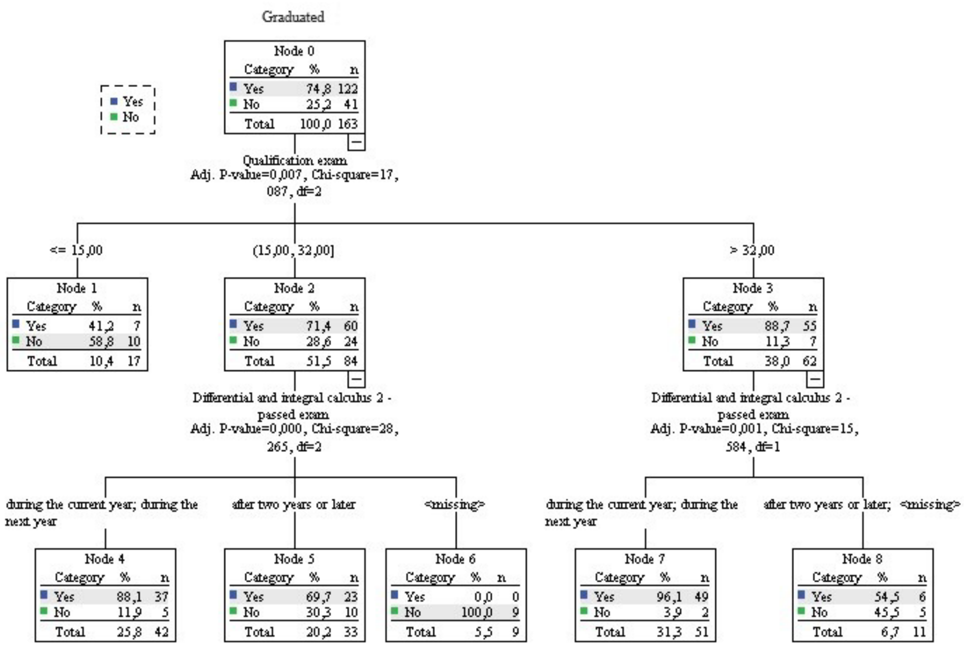

Figure 7. *Generated tree by forcing the variable „Entry exam“.*

Generated rules:

/ Node 1 */.*

IF (Qualification exam NOT MISSING AND (Qualification exam <= 15))

THEN

Node = 1

Prediction = 2

Probability = 0.588235

/ Node 4 */.*

IF (Qualification exam IS MISSING OR (Qualification exam > 15 AND Qualification exam <= 32)) AND (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year")

THEN

Node = 4

Prediction = 1

Probability = 0.880952

/ Node 5 */.*

IF (Qualification exam IS MISSING OR (Qualification exam > 15 AND Qualification exam <= 32)) AND (Differential and integral calculus 2 - passed exam = "after two years or later")

THEN

Node = 5

Prediction = 1

Probability = 0.696970

/ Node 7 */.*

IF (Qualification exam NOT MISSING AND (Qualification exam > 32)) AND (Differential and integral calculus 2 - passed exam = "during the current year" OR Differential and integral calculus 2 - passed exam = "during the next year")

THEN

Node = 7

Prediction = 1

Probability = 0.960784

/ Node 8 */.*

IF (Qualification exam NOT MISSING AND (Qualification exam > 32)) AND (Differential and integral calculus 2 - passed exam != "during the current year" AND Differential and integral calculus 2 - passed exam != "during the next year")

THEN

Node = 8

Prediction = 1

Probability = 0.545455

A regression analysis for predicting the duration of studies (in days) was considered based on the timing (terms) of passing the mathematics courses $LA\&AG_{tie}$, $DIR1_{tie}$, and $DIR2_{tie}$ (the index "tie" indicates the time interval of the exam). The duration of studies has the strongest positive correlation with $DIC2_{tie}$ (0.419), followed by $DIC1_{tie}$ (0,408), while the correlation with $LA\&AG_{tie}$ is weak at 0.139. The positive correlation between the dependent variables was 0.398 (between $LA\&AG_{tie}$ and $DIC1_{tie}$) and 0,277 (between $LA\&AG_{tie}$ and $DIC2_{tie}$). The multiple correlation coefficient R is 0.498, and the coefficient of determination indicates that the regression model can explain 24.8% of the variability in the duration of studies. The coefficient of determination is different from zero (the ANOVA test yielded F = 8.122, p = 0.000), indicating the statistical validity of the regression model.

Based on these three independent variables, the regression equation was obtained:

$$\text{Duration of studies (days)} = 808.352 + 474.412 * LA\&AG_{\text{tie}} + 472.805 * DIR1_{\text{tie}} + 177.009 * DIR2_{\text{tie}}$$

4. DISCUSSION

FACEG initiated research on passing entry exams in 2012 [5] and has been implementing workshops in secondary schools that educate the civil engineering and geodesy profiles and gymnasiums for the past ten years, as well as organising preparation classes. Preparatory classes consist of 20 hours and, before the coronavirus period, were conducted in the classroom for two weeks in June. However, since the onset of the coronavirus period (in 2020) until now, they have been held online for five weeks using Google Meet and Google Classroom applications [15]. The preparation classes comprise 20 online classes (five weeks) through Google Meet and Google Classroom applications [15]. The importance of preparation classes has been recognised among the faculties in the region that organise preparatory courses and/or enable candidates to use the solved tasks from the mathematics entry exam [16-20]. The criteria for enrollment to undergraduate studies in Croatia is based on: achieved success in secondary school (400 points) and passed exams at the state prom test (Croatian language – 50, mathematics up to 450 and physics /not a condition for enrollment, but yields points/ up to 100 points); achievements at competitions – direct enrollment (1000 points)/participation in state-level competitions in mathematics and physics or winning one of the top three places in civil engineering technology/ [20].

Some faculties organise student preparation after enrollment to prepare the students for their future profession before the start of academic classes [21].

After a good selection of candidates at enrollment, it is necessary to research the influence of passing particular exams already in the first year of studying to complete studies successfully. More advanced techniques are required to predict results. The papers [22] and [23] describe creating a prediction model for students' success using Data mining and analysing the factors that influence the achieved level of success. Three methods were tested for data mining: logistical regression, decision tree and neuron nets. The Study [24] aims to provide a step-by-step guidance set for teachers ready to apply the data mining techniques to predict students' success. The successful creation of a model that has 92% correctness in predicting the students' outcome points to the potential of artificial neural nets [25]. The paper [26] analyses data on studying success and exam passing rates in the first year of undergraduate studies for eight generations of students. The goals of the research were to create a predictive model that would enable the identification of students with a high probability of not achieving 30 ECTS points during the academic year and to offer students information on the probability of passing particular exams, i.e., achieving the targeted number of ECTS points at the end of the academic year.

5. CONCLUSION

The candidates yielded solid success during secondary education (during the whole 12-year period of enrollment, the average score was 41.14), while the result of the entry exam was worse (the average score was 25.94). The total average score was 67.08.

Looking into the passing of mathematical exams, it appeared that a more important predictor of the successful completion of the first cycle of studies was the period of passing (when the exam was passed) rather than the mark obtained at the exam.

Passing particular mathematical exams during the current year of studying shows that the prediction of successful graduation is from 82.1% to 91.5%.

The prediction for the successful graduation of civil engineering students is improved by generating rules from the data.

Understanding the factors that influence students' academic success is important due to the design and content of the entrance exams and the relevance of specific academic courses for successful study completion.

It would be interesting to research the effect of individual professional courses on success in studying and duration of studies.

This research can also benefit other academic programs at universities.

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МАТЕМАТИКА И РЕЗУЛТАТИ ПРИЈЕМНОГ ИСПИТА КАО ПОКАЗАТЕЉИ АКАДЕМСКОГ УСПЈЕХА СТУДЕНАТА ГРАЂЕВИНАРСТВА

Сажетак: Од пресудне је важности одабрати висококвалитетне кандидате за упис на факултете и универзитете, фокусирајући се на њихову припрему за будућу каријеру у најкраћем могућем трајању студирања уз одржавање високе стопе дипломирања. Најпоузданији предиктори академског успјеха (дипломирања) примјећују се током тестирања кандидата (пријемних испита) и прве године студија. У овом раду се испитују фактори који утичу на упис кандидата на студијски програм грађевинарства, укључујући успјех из математике (у току прве године студија), статус уписаних студената и завршетак студија. Истражује се и однос између трајања студија и академског успјеха у средњој школи, резултата пријемних испита и способности предвиђања академског успјеха – дипломирања. Циљеви истраживања су били: истражити успјехе постигнуте током средњег образовања међу студентима грађевинарства током 12-годишњег периода; истражити успјех студената у зависности од: врсте завршене средње школе, резултата на квалификационом испиту, статуса студирања, положених математичких предмета које студенти изучавају током прве године студија и испитати могућност коришћења напреднијих техника за предвиђање завршетка студијама.

Кључне ријечи: *предвиђање академског успјеха, пријемни испит, математички предмети, стабла одлучивања, регресиона анализа*