FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 19, Nº 3, 2021, pp. 295-304
https://doi.org/10.2298/FUACE211124022V

Original Scientific Paper

DESIGN OF ATYPICAL FACADE ARCHITECTURAL ELEMENTS AS NOISE REDUCTION BARRIERS - CASE STUDY

UDC 699.844

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Abstract. *The presented work is the result of affirmation of synergistic work of experts dealing with architectural and acoustic design with the aim and purpose of finding an adequate solution for optimal correction of the effect of GHG systems installed on the facade of the subject (case study) office building in Belgrade. Measurements established that the noise of the constructed GHG systems affected the residential building in the immediate vicinity. The effect of the constructed devices (refers to the installed units) of the office building in question in the case when they operate at full capacity was measuring to be about 58 dB (A). The urban zone in which the building is located (Vracar-Belgrade) belongs to the category of "office-residential area" in which the outdoor noise level permitted for the period of day is 60 dB (A), and for the night period is 50 dB (A). Taking into account the stated facts, it has been unequivocally established that GHG systems to a certain extent exceed the permitted noise levels and "endanger" the neighboring observed building. The subject of this professional-scientific research is the design of atypical facade architectural elements as a barrier reducing noise on the example of an office building in Belgrade. The architectural challenge was reflected in the fact that, in addition to designing the facade element which, at the request of the investor must not compromise the architecture of the building, therefore, should be "atypical in architectural design", it must also provide flexibility in applying different variants of acoustic barriers, which in addition to architectonic requirement must provide an adequate response to acoustic requirements. To the satisfaction of the authors, the designed barrier confirmed a successful synergy solution. The adopted architectural-acoustic configuration of the barrier proved to be effective regardless of the type of installed air conditioners, which in some way justifies the initial idea of strong causality of acoustic and architectural design, as a synergistic principle.*

Key words: *Architectural design, Noise reduction barriers, Atypical facade architectural elements, Software prediction,*

Received November 24, 2021 / Accepted December 29, 2021
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1. Introduction

Noise is any undesirable sound that interferes with a person's rest and work. The main sources of noise in the environment are outdoor and indoor noise sources. Outdoor sources of noise are most often road, rail and air traffic, concerts, parks, construction machinery and industry, while in the indoor space noise is produced by air conditioners, transformer stations, discos, concerts. Noise, as a mixture of sounds of different properties, endangers human health in many ways, and it is also one of the biggest polluters of the environment [1], [2]. Noise pollution affects the work environment, and this problem is present not only in residential buildings, but also in schools, universities, offices and hospitals.

According to estimates by European institutions, a large number of people in Europe live in areas where the noise level exceeds the recommended values. It is estimated that 113 million people are affected by long-term traffic noise levels of at least 55 decibels (dB (A)). In most European countries, more than 50% of urban dwellers are exposed to road noise levels greater than 55 dB. The EU considers that long-term exposure to noise levels over 55 decibels is high, while the World Health Organization indicates that this has a negative impact on human health [3].

According to the Law on Protection from Noise [4], anyone who "makes noise emissions is obliged to monitor the emissions and limit its impact within legal regulations." Air conditioners can cause excessive noise levels in a room [5]. In situations where noise cannot be avoided, such as when air conditioners are installed on the facade of a building, it is necessary to perform all necessary interventions to reduce the noise level.

The subject of this scientific research is the design of atypical facade architectural elements as barriers reducing noise on a specific example.

In this paper was performed a comparison of values obtained in two ways, by experimental measurement and software. The performance of the designed barrier was estimated using 3D simulations.

2. Problem Definition

Sound insulation of facade structures has a great effect on conducting noise inside the building [6]. So far, several techniques have been developed based on different approaches to assess barrier effects, using numerical, experimental and empirical methods [7] - [9]. For barrier designers and manufacturers, the contribution of computer modeling makes it possible to predict sound attenuation already in the product design phase [10].

Based on the complaints of the tenants, insight into the specific problem and measurements in the field, it was concluded that the noise level generated by air conditioners placed on the facade of the office building has a disturbing effect. The relationship between the position of the office building where the air conditioners are located and the endangered residential building, as well as the appearance of the air conditioner on the facade of the business building are shown in Figure 1. Based on this, it is possible to consider the position of air conditioners which are a source of noise in respect to adjacent buildings.

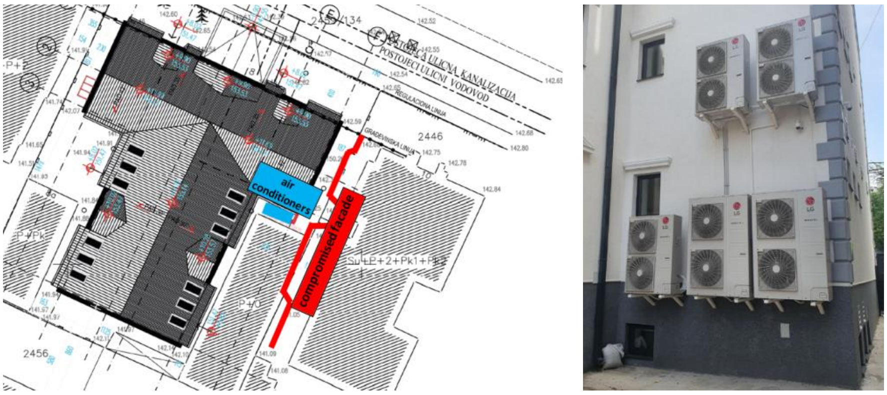

Fig. 1 General plan with the position of the office building where the air conditioners are located and affected endangered facades of the residential building (left) and a photo of the courtyard facade of the office building (right)

After checking the noise level of air conditioners by measuring the noise level at the location of the facility, the criteria for the permissible noise level of the observed air conditioners that they create in the environment were determined, the achieved noise level reduction was checked by software modeling, and the details for realization of the barrier were designed.

Permitted values of noise levels in the urban environment are determined by the document "Regulation on noise indicators, limit values, methods for assessing noise indicators, disturbing and harmful effects of noise in the environment" (Official Gazette of RS No. 75/10). The Regulation defines the limit values of noise indicators according to acoustic zones. The zones are determined by the predominant content of the buildings located in them. The methodology for determining acoustic zones in settlements is defined in the document "Rulebook on methodology for determining acoustic zones" (Official Gazette of RS, No. 72/2010). Definitions of acoustic zones and values of the maximum allowed value of noise levels in the external environment are shown in Table 1. The values from Table 1 refer to the levels measured at the property boundary, which in the urban environment represents the facade of the building.

Table 1 Limit values of outdoor noise indicators

Zone	Area Use	Noise level in dB (A)	
		Day and evening	night
1.	Areas for rest and recreation, hospital zones and recuperation areas, cultural-historical locations, large parks	50	40
2.	Tourist areas, camps and school zones	50	45
3.	Purely housing areas	55	45
4.	Office-residential areas, commercial-residential areas and children playgrounds	60	50
5.	City center, craftsmen, trading, administrative zone with apartments along highways and major and city roads	65	55
6.	Industrial, storage and service areas and transport terminals without residential buildings	At the border of this zone, the noise must not exceed the limit values in the zone it borders	

The zone of the city in which the analyzed facility is located belongs to the category "business-residential areas", which means that the prescribed values of noise levels in the outdoor environment for day and evening are up to 60 dB (A), while for night those values are up to 50 dB). The same Regulation defines the limit values of noise indicators indoors. The prescribed values in the living rooms of apartments (bedrooms and living rooms) with closed windows are up to 35 dB (A) for day and evening, while up to 30 dB (A) for the night. Limit values for noise levels indoors do not depend on the zone in which the residential building is located.

To assess the risk of noise from sound sources located in the external environment, the criterion for outdoor noise according to the appropriate zone of the city must be used. Noise in the premises of buildings cannot be a criterion for assessing the threat from external sources because it depends on variable factors such as the quality of windows in the premises and noise sources located inside the building.

2.1. Analysis of the existing noise state -

The analysis of the current state of ambient noise at the location was performed by a measurement conducted on June 21st, 2021. The measurement was performed in two modes of operation of the noise source:

- when all air conditioners are turned off to define the ambient noise level at the location,
- with all outdoor units of the device operating at their maximum power.

The purpose of this measurement is to obtain data for calibration of the software model and algorithm with which the calculation of noise levels on the facade of the residential building was performed.

The measured values of the noise level in the circumstances when all air conditioners are operating at the maximum power show that the noise level exceeds the allowed value for the night period which is 50 dB (A). For example, the measured value of the equivalent noise level at one measuring point was 58.5 dB (A). Subjectively (by listening), the sound of the outdoor units of the air conditioner is clearly recognized as dominant in the sound that is heard on the location.

Measurement of noise levels in circumstances when all air conditioners are switched off shows that the noise level at the used measuring points is approximately in the range of 46-49 dB (A). Subjectively (by listening), it was estimated that the existing ambient noise predominantly originates from the air conditioners in the residential building, where there are four outdoor units, one of which is of slightly higher power.

A detailed calculation of the noise level in the outdoor environment, which refers to the condition without a built-in protective barrier, was performed for two variants of outdoor units. One relates to devices that are installed on the facility, and the other to devices from another manufacturer that are provided by the designed solution.

Five LG devices are installed at the office building, in the following order: ARUN 120LSS0, ARUN 100LSS0, ARUN 80LSS0, ARUN 60LSS0, ARUN 50LSS0. The design of the building comprised DAIKIN devices, respectively: RXYSQ12TY1, RXYSQ10TY1 ("Ground floor" systems), RXYSQ8TY1 ("Attic 1" systems), RXYSQ6T8Y ("Basement" systems), RXYSQ5T8Y.

The calculation of the noise level on the facade of the neighboring residential building in its current state with built-in devices manufactured by LG, even when all devices are working at maximum power, shows values around 55 dB (A), and in some zones exceeds 60 dB (A).

The calculation of the noise level with the designed devices manufactured by DAIKIN shows that the noise level on the most affected parts of the facade would be on average lower by 1-1.5 dB compared to the built-in solution with LG devices. In both cases, considering the constructed and designed solutions, when working at maximum power, the noise level on the facade of a residential building exceeds the values prescribed for the night period. From the aspect of affecting a residential building with noise, there is practically no difference between them because 1-1.5 dB is within the limits of measurement uncertainty when measuring noise levels.

The measurement results showed that the level of that noise exceeds the permitted value.

3. Design as an Architectural and Acoustic Challenge

Due to the specific configuration of buildings and the position of outdoor units, calculations have shown that it is necessary to form a barrier that maximally shields the units. The barrier on the inside must be lined with a highly absorbent material. The efficiency of a noise barrier largely depends on its geometry [11]. Figure 2 shows the appearance of the southern facade of the office building with a barrier, while Figure 3, Figure 4 show the details of the construction of the designed protective barrier solution to reduce the effects on the residential building

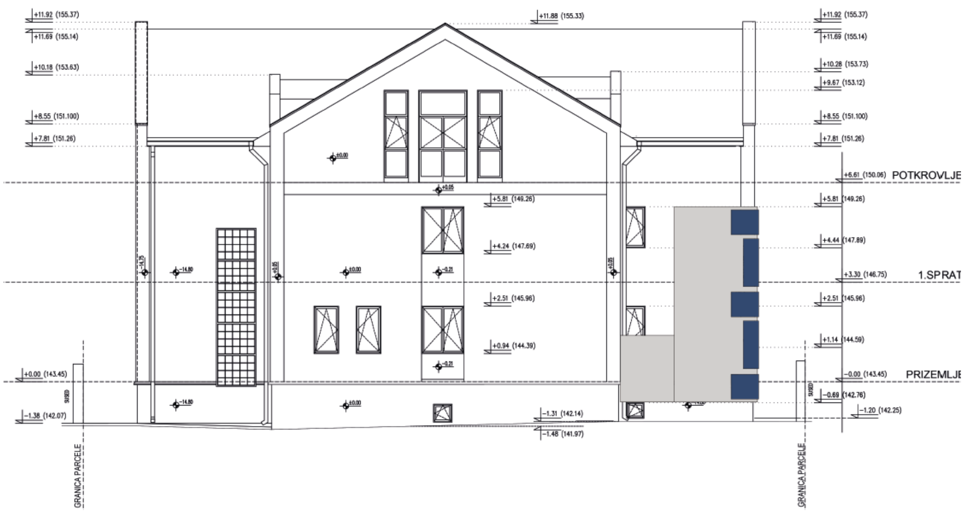

Fig. 2 Appearance of the southern facade of the office building with the installed barrier

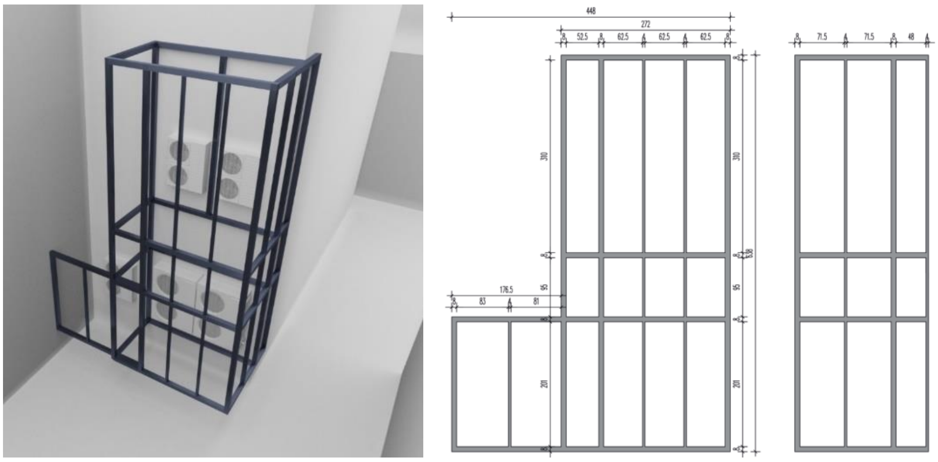

Fig. 3 Appearance of the steel structure of the designed barrier (left) and dimensions of the steel structure (right)

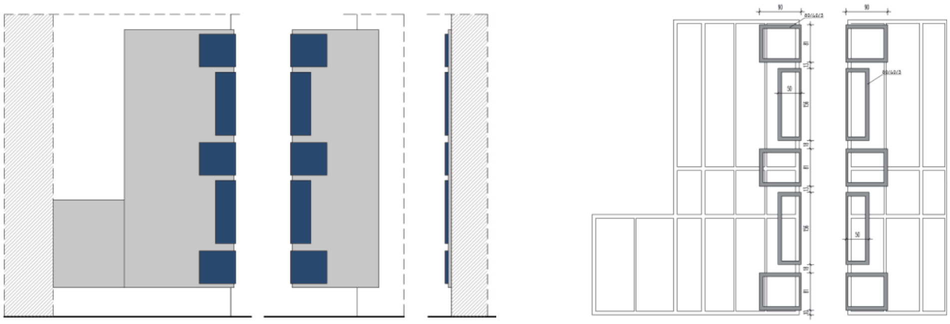

Fig. 4 Appearance and dimensions of facade barrier structures

For the designed barrier, noise level calculations were performed on the facade of the adjacent building for the case when the outdoor units operate at maximum power. The calculation results show that the noise levels on the facade of the neighboring building with a built-in barrier do not exceed the values of 50 dB (A). This satisfies the criterion of noise in the outdoor environment for the residential-business zone for both day and night mode. The same calculation was made for the case when DAIKIN air conditioners, which are planned by the design, would be installed. From the results presented in Annex 5, it can be seen that the differences in the values of noise levels are up to 1.5 dB, as in the case without a protective barrier. This difference is within the measurement uncertainty that is inherent in the procedure of measuring sound levels.

4. MEASUREMENTS AS A REFERENCE POINT

This section presents the results of the control measurement of noise of outdoor units of air conditioners in the current state. Figure 5 shows the measuring points where control measurements were performed. The measurement was performed at two measuring points positioned on the upper edge of the wall that separates the plot of the office building from the adjacent plot of the endangered residential building. The measurement sites and the obtained results are shown in Figures 5 and Figure 6.

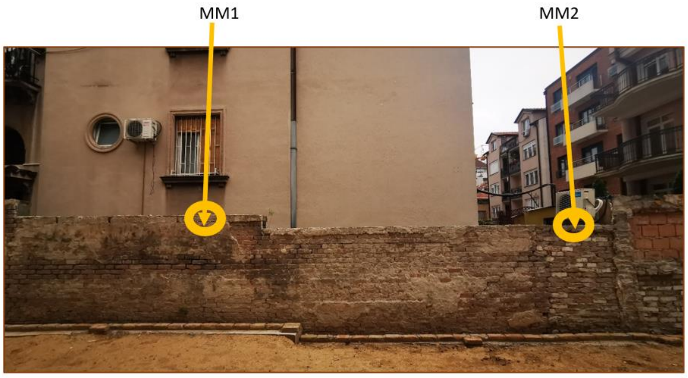

Fig. 5 Photograph of the wall separating the plot of the business building and the plot of the neighboring residential building; the positions of the measuring locations places are marked (view from the side of the office building)

Figure 6 shows the measured 1/3 octave spectra of the equivalent noise level at the measuring positions MM1 and MM2 for the case when all air conditioners are turned off and when they are all on and working at full capacity. The graph also shows the equivalent A weighted noise levels for both measuring positions with and without air conditioning on.

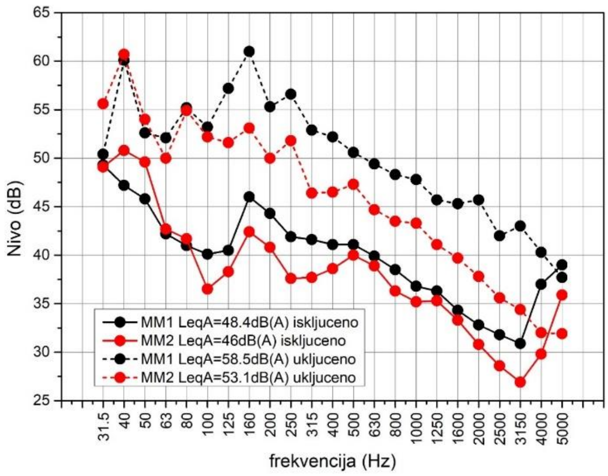

Fig. 6 Results of noise level measurements at two measuring points (MM1 and MM2) when all air conditioners are switched off, and when all are switched on and working at full capacity.

5. Simulations

The results of the calculation of the noise condition on the entire facade of the residential building are shown in the figures. Figure 7 (left) shows the result for the case such as the current state of the building, i.e. with built-in devices manufactured by LG, and Figure 7 (right) for the case of devices manufactured by DAIKIN that are planned by the design. The images show the calculated values of the noise level in the zone directly in front of the facade in a certain grid. All values are in dB (A).

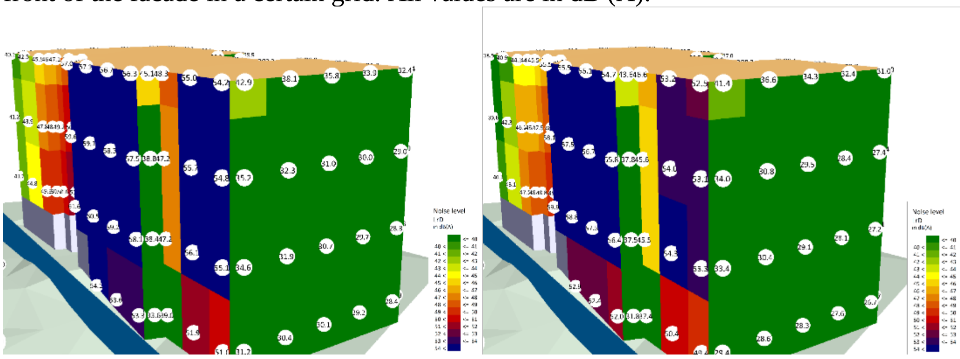

Fig. 7 The result of the calculation of the equivalent noise level on the facade of the neighboring residential building in the case of LG (left) and DAIKIN (right) outdoor air conditioning units, during their operation at maximum capacity; all values are in dB (A).

6. Calculation of Noise Condition on the Façade of a Residential Building with a Protective Barrier

The results of the calculation of the noise condition on the entire facade of a residential building with a designed protective barrier are shown in the figures. Figure 8 (left) shows the result for the case of the current state of the building, i.e. with built-in devices manufactured by LG, while Figure 8 (right) shows the result for the case of devices manufactured by DAIKIN that are planned by the design. The images show the calculated values of the noise level in the zone directly in front of the facade in a certain grid. All values are in dB (A).

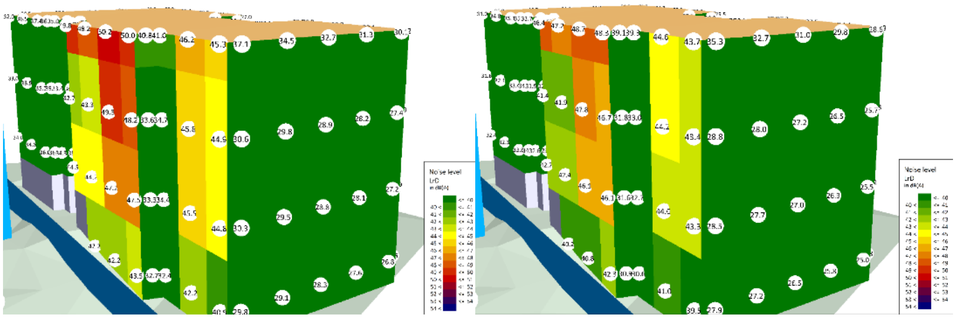

Fig. 8 Calculated values of equivalent noise level on the facade of the nearest building with built-in LG (left) and DAIKIN (right) units and a designed barrier

7. Conclusions

Designing atypical façade architectural elements as barriers to noise, in addition to being a great challenge for architects, also contributes to the improved acoustic comfort of people. In this paper, a comparison of values obtained in two ways, by experimental measurement and software was performed. The performance of the designed barrier was estimated using 3D simulations. During the design, different variants of barriers were considered, which, in addition to architectural principles, must also meet acoustic requirements. The calculation shows that the adopted barrier configuration is effective regardless of the type of air conditioner installed, given the small difference in the maximum noise levels they produce.

Acknowledgments: *We thank everyone who in any way participated in the preparation of this work and who through their advice and experience contributed to writing and publishing this work.*

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PROJEKTOVANJE ATIPIČNIH FASADNIH ARHITEKTONSKIH ELEMENATA KAO BARIJERA ZA SMANJENJE BUKE - STUDIJA SLUČAJA

Prikazani rad je rezultat afirmacije sinergijskog delanja stručnjaka koji se bave arhitekatonskim i akustičkim dizajnom sa ciljem i u svrhu pronalaženja adekvatnog rešenja za optimalnu korekcije uticaja GHG sistema postavljenih na fasadi predmetnog (studija slučaja) poslovnog objekta u Beogradu. Merenjima je ustanovljeno da su izvedeni GHG sistemi ugrožavali bukom stambeni objekat u neposrednoj blizini. Uticaj izvedenih uređaja (odnosi se na ugrađene jedinice) predmetne *poslovne zgrade u slučaju kada rade punim kapacitetom merenjem je utvrđen na vrednost od oko 58 dB(A). Urbana zona u kojoj se nalazi objekat (Vračar-Beograd) spada u kategoriju „poslovno-stambenog područja" u kojoj su dozvoljeni nivo buke u spoljašnjoj sredini za period dan 60 dB(A), a za period noć 50 dB(A). Uzimajući u obzir navedene činjenice nedvosmisleno je utvrđeno da GHG sistemi u određenoj meri premašuju dozvoljene nivoe buke i "ugrožavaju" susedni posmatrani objekat. Predmet ovog stručno-naučnog istraživanja predstavlja projektovanje atipičnih fasadnih arhitektonskih elementa kao barijera za smanjenje buke na primeru poslovnog objekta u Beogradu. Arhitektonski izazov ogledao se u tome da se, pored osmišljavanja fasadnog elementa koji, na zahtev investitora ne sme narušiti arhitekturu objekta, dakle, treba biti "atipičan po arhitektonskom dizajnu", mora pružiti i fleksibilnost apliciranja različitih varijanti akustičkih barijera koje pored arhitektonskih zahteve moraju dati adekvatan odgovor i na akustičke zahteve. Na zadovoljstvo autora dizajnirana barijera je potvrdila uspešno sinergijsko rešenje. Usvojena arhitektonsko-akustička konfiguracija barijere pokazala se efikasnom nezavisno od tipa instalisanog klima uređaja, što u neku ruku opravdava inicijalnu ideju o jakoj kauzalnosti akustičkog i arhitektonskog dizajna, kao sinergijskog principa.*