Строительные материалы и изделия

Construction Materials and Products

journal homepage: https://bstu-journals.ru

ISSN 2618-7183

DOI: 10.58224/2618-7183-2023-6-6-9

Vernacular architecture in the space of a modern city, based on deep learning methods and three-dimensional structural analysis

Krestinenko N.V.*[1]

[1] Russian State Pedagogical University named after. A.I. Herzen, Russia.

Abstract. This research paper describes the process and results of a project to automatically classify historical buildings using aerial photography and satellite imagery. New computational scientific methods and the availability of satellite images have created more opportunities to work on automated recognition of pieces of historical architecture. In this regard, the convolutional neural network (CNN) is the main classification approach within the project. As a result, the trained model is tested using a validation data set and has a roughly 98% accuracy. In addition, being affected by urbanization and other factors, local architectural heritage faces the challenge of introducing innovations for sustainable development, with originality and authenticity being preserved in redesign and planning. Thus, this study uses a visualized quantitative analysis to analyze the research trends in Russian vernacular architecture and study new ways of coexistence between vernacular architecture, object perception and cultural ecology. The most important task of this study is to analyze the theory of coordination between the emotion social and cultural structure and the cultural ecosystem in vernacular architecture. The main contribution of this study is the proposed concept of a subjective-cultural eco-design system for vernacular architecture sustainable development to establish a 3D structural analysis design paradigm and evaluation analysis matrix, and to ensure that vernacular architecture demonstrates the ability to self-renew by continuous exchange and revision in the dynamic cycle of the current design system.

Keywords: vernacular architecture, neural networks, learning, structural analysis, marginal culture, inclusion, inclusivity

Please cite this article as: Krestinenko N.V. Vernacular architecture in the space of a modern city, based on deep learning methods and three-dimensional structural analysis. Construction Materials and Products. 2023. 6 (6). 9. DOI: 10.58224/2618-7183-2023-6-6-9

*Corresponding author E-mail: krestinenko@bk.ru

Received August 15, 2023; Received in revised form October 2, 2023; Accepted December 13, 2023

1. INTRODUCTION

Over several stages, debates have continued among theorists about the relationship between architecture and society, the role of structures in social change, and the ethical responsibility of the architect for the influences that influence his activities in the world around him. The faction, which can be called “classists,” determines the aesthetic dimension of objects and the priority of professional implementation: the work of architects is to create masterpieces and show self-worth; Social and economic contexts, as well as the motives of the customer, should be taken into account only secondarily or not at all.

The “classicists” are opposed by critical theorists who believe that architecture is not only not autonomous from society with all its features and, inevitably, vices, but is also actively involved in social processes [1].

Architecture, from the general layout of cities to the most insignificant design nuances of individual buildings, frames and shapes social life. Critical theorists emphasize that, historically, architecture has had a close relationship with those who wield influence in society, which means that even the most outstanding objects created by architects had to convey the meta-message of the client. As G. Bristol of the Canadian Center for Architecture and Human Rights notes, “architecture has always been linked in some way to power, whether it was building houses for God (or at least His high priests) or, more recently, building cathedrals to Mammon and various forms of conspicuous consumption” [2].

Looking ahead, it is worth noting that such a view, for all its heuristic value, seems overly radical, if only because it excludes the absolute majority of objects ever built from the sphere of architecture. A more balanced approach when it comes to the development of inclusive and emancipatory architecture, as in the case of other social challenges, should not so much criticize the status quo, but rather look for ways to turn its strengths to the common benefit - not to deny the good in the existing, but to create it is a benefit shared by as many people as possible, not just a privileged group.

One can agree with the founder of the WikiHouse project and a leading figure in the movement for the egalitarianist of architecture, A. Parvin, who argues that “our interest should be less about the transgression of the normative and more about the reinvention of what is normal... the most radical thing we can do, – to democratize it: to ask whether architecture today, for the first time, can have as its clients not 1%, but 100% [of people]” [3]. As more architects realize the problematic nature of the current situation, they are beginning to look for alternatives.

Some of them are inclined to the need to abandon the monologue of the profession and move to the “post-professional era” (H. Sadri), others predict the advent of “architecture after the architects” [4] thanks to the development of artificial intelligence and new technologies that equalize professionals and enthusiasts. Trying to summarize the spirit of the times, the British theorist T. Kaminer stated that the use of “iconic buildings and impressive structures to “sell” cities as globally [in demand] and keeping pace with the market, to sell housing to international speculators, to add a gloss of solidity and entertainment frankly left a bad aftertaste for commercial endeavors” [5].

In response, more architects began to turn to "increased citizen participation, to 'everyday' architecture, DIY, and forms of architecture that were not discredited by obvious connections or dependence on neoliberalism" [5].

Such an appeal, however, is not something new, if by such we mean the emergence of a new phenomenon, rather this process is more accurately called emancipation, during which all those who imagined, designed and built houses without being part of a professional workshop are given a voice. B. Rudofsky drew attention to the omnipresence of these silent builders and the extremely narrow optics of professional architects who stubbornly do not notice their existence. last century [6], but only recently the study of vernacular (“folk”, “anonymous” [7]) architecture began to enjoy wide recognition.

In a general sense, vernacular, or “vernacular” architecture, is [8-11]: an umbrella concept that refers to any objects built without the participation of professional architects: traditional Aboriginal housing; a hastily assembled refugee tent; a temporary shelter built from improvised materials by homeless people; a country house of a poor family from the Russian province with an improvised fence made of skis and bedposts; the cottage of the new bourgeoisie, who fundamentally refused the services of an architect in order to single-handedly realize his childhood dream of a castle.

Vernacular architecture is a heritage repository and a country's authenticity representation, while the vernacular architectural heritage having its national and regional identity is an integral part of traditional culture [12]. As a critical research object, the architectural heritage of local residential buildings should not only have ethnicity and folklore identity in reconstruction planning, but also consider human-centered settlements and current environmental problems [13].

Vernacular architecture is a traditional culture transmitter. People here are inherent determinants of sustainable architectural culture development. Hence, people make it possible for modern architectural concepts and methods, as well as residents' views to promote peer-to-peer exchange of ideas and cultural spirit clash [14].

The materials and methods section of the given article considers the neural network training model to reveal the architectural concept that shaped the design of historical buildings.

A subject-culture ecological design system is further considered. It gives an impetus to vernacular architecture to create an excellent sustained growth cycle and expand cultural values and building exploitation based on an evaluation matrix for analyzing the spatial design factor loading

2. METHODS AND MATERIALS

This article proposes a CNNs-based binary classification model to recognize the features peculiar to historic buildings in Google Earth images. Convolutional neural networks are biologically inspired networks used in computer vision to recognize images and detect objects. Within the convolutional neural network architecture, each network layer is three-dimensional, with spatial dimensions and depth corresponding to the number of objects. The concept of the single layer depth in a convolutional neural network differs from the depth in terms of the number of layers. On the input layer, these objects correspond to RGB color channels.

Moreover, in covert channels, these patterns reflect hidden target maps that encode different image shapes. The input layer will have a depth set to unity if the input data are presented in different shades of gray, but later layers will still be three-dimensional [15]. Deep convolutional neural networks were used as an effective model in computer vision. For example, they are commonly used to process images, recognize objects, locate objects, and even classify text. Recently, network efficiency has surpassed human efficiency in classifying images [16]. Fig. 1 shows one of the earliest convolutional neural networks.

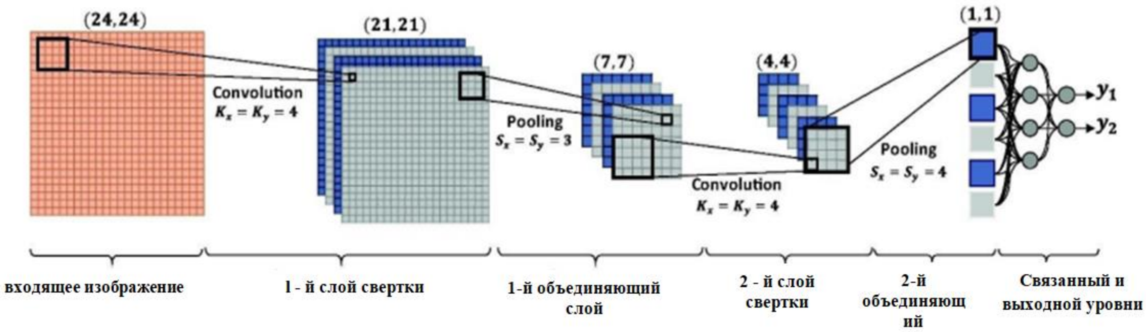

Fig. 1. One of the earliest convolutional neural networks [17].

Deep convolutional neural networks, abbreviated as CNNs or ConvNets, are a special neural network category specializing in processing data with grid topology, such as images. In CNN, a convolutional layer is responsible for applying one or more filters to data. Some layers separate convolutional neural networks from other neural networks [18, 19]. Each convolutional layer includes one or more filters known as convolutional cores. Combining layers helps minimize the input object dimension, thereby reducing the maximum number of parameters and model complexity. One of the most commonly used combinators is maximum union. As the name suggests, this strategy applies to the maximum pool return only [20]. Fig. 2 shows two types of layers used in the model. Conv2d and Maxpooling2d are CNNs layers used in the model five times to change 300x300 images to 7x7 images and recognize photo patterns.

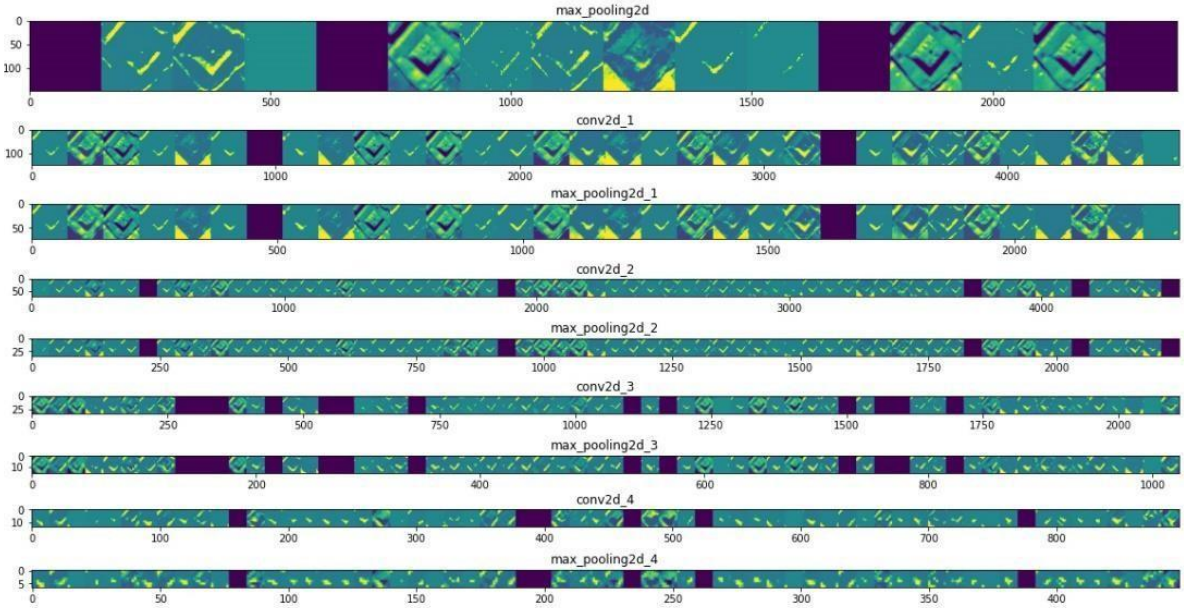

Fig. 2. Nine layers used in our CNN model.

Conv2d layers use multiple filters to recognize patterns in photos. In addition, the Max-pooling2d layers reduce the photo size by converting every 4 pixels into a single new pixel and applying the maximum value of those 4 pixels to the new pixel. The input photos were 300 × 300 pixels in size, but they were converted to 7 × 7 pixels in the last CNN layer.

The neural network structure consists of simultaneous convolutional layers 1 ∈ [1, L].

For each convolutional layer, an input data map (image) is collapsed by a series of cores Wi = $\{W^1, \dots, W^k\}$ and bj = $\{b^1, \dots, b^k\}$ to create a new target map. The nonlinear activation function f is then added to this target map to obtain the output Y_l, which is the input for the next layer. The output map n-th function peculiar to the 1st layer can be described by equation (1) [17]:

$$Y_l^n = f\left(\sum_{k=1}^{k} W_l^{n,k} \times Y_{l-1}^k + b_l^n\right). \quad (1)$$

While training the network under question, the goal was to reduce the sample loss function showing the effectiveness of training image classification. We used the Binary_Cross entropy method to calculate the loss function over the entire training datasets.

The loss function H for the N training samples may be described as in equation (2):

$$H_p(q) = -\frac{1}{N}\sum_{i=1}^{N} y_i \times log\, log\left(p(y_i)\right) + (1 - y_i) \times log(1 - p(y_i)). \quad (2)$$

In which y is a mark for each training image (0 or 1), and p (y) is the algorithm response to a particular image. The average value of all image loss functions is also known as a cross-correlation function. The Binary_Crossentropy loss function model is a solution for binary classification problems such as our historical or non-historical classification model.

To optimize the W and b values in equation (1), we used the RMSProp gradient descent algorithm for each period. RMSProp has been implemented into the Keras system (https :/github.com/keras-team/keras) and we set the initial learning rate at 0.001. To avoid over-fitting, we used a 0.5 probability dropout layer in the CNN model, prior to the hidden layer in addition to the complement. We have training data that was a 300x300x3 pixel 3D patch. Color image data are encoded as integers in a set of 0 to 255 for each red, green, and blue. We divided each pixel value by 255 to scale the data to the [0.1] range, since neural networks are more productive under a limited and relatively uniform range of values.

We used 100 as the total number of periods for training and monitoring the model to assess its fitting and efficiency in the course of the training process. In each period, the machine learns through dataset samples. In addition, the loss function is calculated upon completion of training. The machine tries to reduce losses in the next period.

After the required data is obtained, an evaluation matrix is built to analyze the factor loading for the historical building spatial design.

3. RESULTS AND DISCUSSION

1. Design concept for 3-D structured analysis

Functioning as subjective-cultural eco-design peculiar to vernacular architecture, the emotional model feedback mechanism consistently connects the objective, cultural and spatial dimensions. It builds a paradigm of three-dimensional structural analysis for the subjective-cultural eco-design system. This structure degrades the external input and internal output factors of the system in terms of objective, cultural, and spatial dimensions. The objective dimension then serves as the basic processing level of the system, evaluating and assessing each cultural and spatial dimension sublevel. As shown in Figure 3, each factor axis in each dimension consists of a plurality of squares representing the relationship between each cultural factor, each spatial factor, and the subject's perception. In rectangular spatial coordinates, intertwined factor axes form a three-dimensional, natural, and visualized design analysis structure that clarifies theories, design methods, and evaluation approaches applied to a subjective-cultural eco-design system. It provides a clear and solid foundation for design research on vernacular architecture redesigning, as well as a more systematic and intellectual argument and the approach to preserve and develop current vernacular architecture.

2. Evaluation analysis matrix

In the paradigm of designing three-dimensional structural analysis of the subjective-cultural eco-design system peculiar to vernacular architecture, there is an evaluation matrix for analyzing the spatial design factor loading. For example, V15 in Table 1 reflects evaluation and a comprehensive analysis of visually perceived objective dimension depending on the combination of cultural and spatial factors. As shown in Table 1, the matrix uses five sensory factors as the key evaluation factors for object dimension. It represents multiple visual patterns of combined cultural and spatial dimensions. In each template, visual perception factors will be analyzed to formulate appropriate questions, as well as assess and rank them by satisfaction and care measuring scales.

The evaluation matrix provides a transparent and standardized, reliable basis for the requirements imposed on designing the respective spatial scale ratios and the weighted coefficient of each scale factor. Table 2 shows the population preferences in choosing the functional scale of each room, with regards to visual factors. Based on the table analysis, different functional spaces of premises can be derived, as well as significant factors affecting people's spatial demand. Meanwhile, the further use of the evaluation matrix for clarifying each model promotes analysis of key evaluation factors corresponding to the most important elements of local building spatial design, thus forming a database with design evaluation factors valid for local buildings.

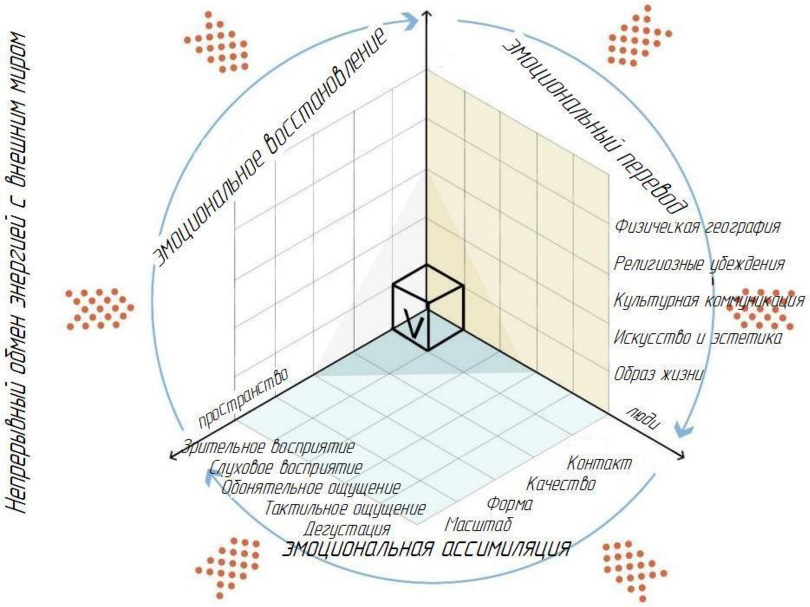

Fig. 3. Subjective-cultural eco-design systems incorporate the concept of three-dimensional structural analysis.

Table 1. The visual factor evaluates the combination of factors in the cultural and spatial dimensions using thr matrix*.

Cultural aspects Spatial aspects	Physical geography	Religions views	Cultural communication	Art and aesthetics	Lifestyle
Scale	Vll	V12	V13	V14	V15
Form	V21	V22	V23	V24	V25
Quality	V31	V32	V33	V34	V35
Contact	V41	V42	V43	V44	V45

*"V15" is an analysis of factor combination in the "V" model in Figure 1

Table 2. Under visual factors, the evaluation analysis of the V15 model factor combinations was conducted.

V15	Space requirements	Lifestyle	Satisfaction measurement				Ranking by importance		
Scale	Public space	1. Separate kitchen space for 1-2 people	2	3	4	5	1	2	3
		2. Open kitchen space	2	3	4	5	1	2	3
		3. Sufficient storage space	2	3	4	5	1	2	3
		4 Compact bathroom/ multi-purpose room	2	3	4	5	1	2	3
	Private space	5. Compact bedroom space	2	3	4	5	1	2	3
		6. Spacious bedroom (with private bathroom)	2	3	4	5	1	2	3
	Functional space	7. High-ceilinged and open living room/terrace	2	3	4	5	1	2	3
		8. Vegetable/flower garden	2	3	4	5	1	2	3
		9. Rational drainage system	2	3	4	5	1	2	3

The old fishing village Ustreka located in Starorussky district of the Novgorod region, on the banks of the Ilmen river, and existing for more than 500 years will be used as an illustration of the "single print" architectural form. The "single print" architectural form is typical of the traditional courtyard in the Novgorod region. Since the layout and the overall building appearance are similar to a square, the building was called a "single print" (Fig. 4).

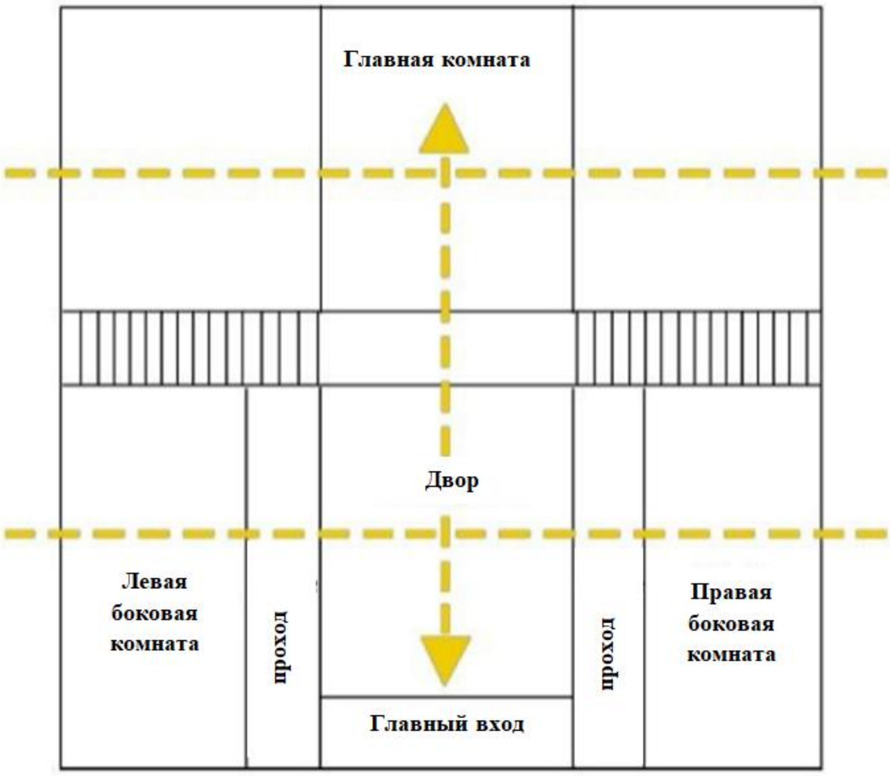

Fig. 4. «Single print» architectural form.

In addition, the building layout is based on the principle of central symmetry. As part of this study, we inspected 43 residential buildings in this fishing village, as well as held in-depth interviews and surveyed 135 village residents. The basic spatial elements of the original "single print" architecture include the main house, side extensions, gates, courtyard, corridors and stairwells. The modern spatial layout is very similar to it and corresponds to the new residents′ necessities of life. Changing the "single print" architectural form implies that the interaction between the residents′ perception and social culture is crucial for determining the vernacular architecture form. In this regard, this study analyzes and explores the fundamental relationship of the "single print" architectural form with 135 data samples, with the residents' spatial demand represented in the V15 model being an example. The results show that for a middle-aged and elder (45 and older) target group, the proportion of residents assessing their lifestyle spatial rates by visual factors is ranked as follows: **functional space > public space > personal space**. When the target group is youth (under 45), the proportion of residents assessing their lifestyle spatial rates by visual factors is: **functional space > personal space > public space**, as shown in Figure 5. This comparison clearly shows that residents' need for functional space is the main reason for the change in the core spatial elements of the original "single print" building. The pie chart in Figure 6 shows that among the functional space needs, the residents lay a particular emphasis on bathrooms/multi-purpose rooms and kitchens. In addition, middle-aged and elderly people are more concerned with arranging small vegetable /flower gardens and drainage systems in public places. On the contrary, young people are more concerned with bedroom layouts in their private rooms.

Fig. 5. The satisfaction rating of the V15 Model Space.

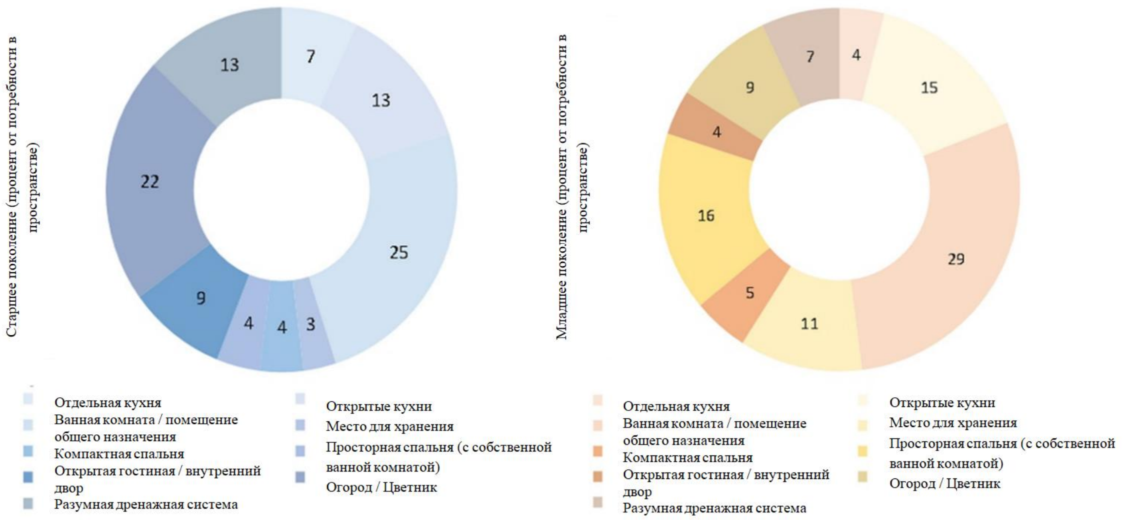

Fig. 6. The ratio of the needs of elderly and young people in the space of the V15 model.

In this study, the building layout was developed based on the analysis above.

As shown in Fig. 7, comparing the current building layout with the original one reveals that the layout of private rooms located on the ground floor on both sides of the building has been adjusted for functional areas.

Fig. 7. Modern layout.

It is worth noting that the case mentioned above shows only one perceptual factor axis in subjective measurement within the evaluation analysis matrix. The most striking observation that can be made from the data comparison is that each perceptual measurement of an object dimension is a system of methods that includes, major or minor, a set of steps such as design purpose, design factors, solutions, and design evaluation. Forming, creating and developing these specific methods will provide more systematic, scientific and theoretical support for vernacular architecture preservation and sustainable development.

4. CONCLUSION

Recognizing historical buildings in low-quality aerial photography is a time-consuming and problematic task for researchers working with historic cities. Thus, the contribution of the current research to the community of planners and urban designers, renovators and architects has promoted new experimental research on the use of interdisciplinary sciences in developing an approach for distinguishing historical buildings from non-historical ones.

The idea of writing the current article also lies in the process of reflection on the new ways of vernacular architecture coexisting with residents' subjective perception and social culture, as well as in the study of a more systematic and scientific theory and design model for vernacular architecture sustainable development. Revising the literature and research held by Russian scientists on vernacular architecture, it can be easily seen that these are mainly focused on three aspects: cultural, functional and economic.

(a) **Cultural dimension**: analysis and preservation of architectural culture and residential building spatial layout in terms of history, physical geography, spatial and temporal distribution characteristics, cultural genes and digital technologies, based on anthropology and ethnography, cultural studies and archeology.

(b) **Functional level**: design and planning of structural characteristics, life cycle and impact of residential buildings on the environment in terms of spatial structure, spatial function, habitat, fire and earthquake prevention, as well as environmental sustainability, based on architecture, environmental behavior and ecology.

(c) **Economic dimension**: The focus is on the tourism industry, the countryside, and the incorporation of vernacular architecture into the industry modernization system to increase its economic value, which is also a replacement strategy actively promoted in Russia.

In the dynamic cycle of the subjective-cultural eco-design system, vernacular architecture can undergo self-renewal in "continuous exchange-revision," no longer waiting for it to be interpreted as "antiques." The subjective-cultural eco-design system encourages vernacular architecture to create a perfect cycle of sustainable growth and expansion of cultural values and practical use of buildings. Thus, it can bring more profound social, environmental and cultural benefits. However, there are still many areas in this design research framework that need close examination and improvement.

Vernacular architecture, within the subjective-cultural-ecological design system, has the capability to continuously exchange and revise itself, rather than relying on interpretation as mere antiques. By actively participating in the cultural identity and emotional transmission of the home, vernacular architecture exhibits dynamic characteristics. The implementation of a subjective-cultural-ecological design system not only stimulates sustainable growth within vernacular architecture but also enhances its cultural value and practicality.

Conducting fieldwork on samples from different regions, diverse cultures, and multiple forms as much as possible is the hope of this study. This will allow for a more profound social, ecological, and cultural benefit. However, there are still many parts of this design research framework that require detailed refinement and improvement. One of the main limitations of this study is the inability to collect sample data from more regions due to external factors such as epidemic control. This hinders further validation and refinement of the designed research framework.

The authors aim to enrich the theoretical system of sustainable development of contemporary vernacular architecture in Russia and the new pattern of rural by forming a set of standardized and flexible theories and design models for residential buildings. This will be achieved by extensively researching ideas and methods with a large amount of sample data.

5. ACKNOWLEDGEMENTS

The study was funded by an internal grant from the Russian State Pedagogical University named after A.I. Herzen (Project No. 5VG)

REFERENCES

[1] Jones P. Architecture, Time, and Cultural Politics. Cultural Sociology. 2020. 14 (1). P. 61 – 79. DOI: 10.1177/1749975520905416

[2] Bristol G. The Trouble with Architecture. In: “Neo-Liberalism and the Architecture of the Post Professional Era” by H. Sadri (ed.). 2018. P. 11 – 29.

[3] Parvin A. Architecture (and the Other 99%): Open-Source Architecture and Design Commons. Architectural Design. 2013. 83 (6). P. 90 – 95. DOI: 10.1002/ad.1680

[4] Ingarden K. From Architecture Without Architects to Architecture After Architects. Technical Transactions. 2019. 8. P 19 – 29. DOI: 10.4467/2353737XCT.19.078.10857

[5] Kaminer T. The Efficacy of Architecture: Political Contestation and Agency. London: Routledge, 2017. DOI:10.4324/9781315693750

[6] Rudofsky B. Architecture Without Architects: A Short Introduction to Non-Pedigreed Architecture. Albuquerque, 1987.
[7] Dolgova E.D. Aesthetics of anonymous architecture. Bulletin of SGASU. Urban planning and architecture. 2016. 2 (23). P. 91 – 95. DOI: 10.17673/Vestnik.2016.02.17
[8] Gómez Martínez V., Ma D., Pellegrini P., Reimão Costa M. Vernacular Architecture and Cultural Identity in Shrinking Rural Settlements. ACE: Architecture, City and Environment. 2022. Vol. 17(50). 11389. DOI: 10.5821/ace.17.50.11389
[9] Venturi R, Brown S.D, Eisenour S. Las Vegas Lessons. Moscow: Strelka Press. 2015.
[10] Skrede J., Andersen B. Visualising the past for the future: a social semiotic reading of urban heritage, Social Semiotics. 2022. DOI: 10.1080/10350330.2022.2035654.
[11] Rozin V.M. The idea of building a new humanitarian discipline – "narrative semiotics". Culture and Art. 2022. 4. P. 78 – 93. DOI: 10.7256/2454-0625.2022.4.37955
[12] Roper R. Private Visions: Outsider Art on Utah's Cultural Landscape. Utah Historical Quarterly 1 January 2020. 88 (1). P. 58 – 76. DOI: https://doi.org/10.5406/utahhistquar.88.1.0058
[13] Mekonnen H., Bires Z., Berhanu, K. Practices and challenges of cultural heritage conservation in historical and religious heritage sites: evidence from North Shoa Zone, Amhara Region, Ethiopia. Herit Sci. 2022. 10. 172. DOI: 10.1186/s40494-022-00802-6
[14] Volodina A.V. Vernakular in culture: a shared local experience language. Current problems of theory and history of art. 2022. 12. P. 642 – 653. DOI: 10.18688/aa2212-07-51
[15] Soori M., Arezoo B., Dastres R. Artificial intelligence, machine learning and deep learning in advanced robotics, a review. Cognitive Robotics. 2023. 3. P. 54 – 70. DOI: 10.1016/j.cogr.2023.04.001
[16] He K., Zhang X., Ren S., Sun J. Deep Residual Learning for Image Recognition. In Proceedings of the 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR). Las Vegas, NV. USA, 27-30 June 2016. P. 770 – 778. DOI:10.1109/cvpr.2016.9
[17] Kiranyaz, S.; Avci, O.; Abdeljaber, O.; Ince, T.; Gabbouj, M.; Inman, D.J. 1D convolutional neural networks and applications: A survey. Mech. Syst. Signal Process. 2021. 151. 107398. DOI: 10.1016/j.ymssp.2020.107398.
[18] Singh P., Manure A. Introduction to TensorFlow 2.0. In Learn TensorFlow 2.0: Implement Machine Learning and Deep Learning Models with Python. Apress: Berkeley, CA, USA, 2020. P. 1 – 24. DOI: 10.1007/978-1-4842-5558-2_1
[19] Moscoso-García P., Quesada-Molina F. Analysis of Passive Strategies in Traditional Vernacular Architecture. Buildings. 2023. 13 (8). 1984. DOI: 10.3390/buildings13081984
[20] Savaşkan M.O., Özener O.Ö. H-BIM applications for vernacular architecture: a historic rural house case study in Bursa, Turkey". Engineering, Construction and Architectural Management. 2022. Vol. ahead-of-print No. ahead-of-print. DOI: 10.1108/ECAM-01-2022-0017

INFORMATION ABOUT THE AUTHOR

Krestinenko N.V., e-mail: krestinenko@bk.ru, ORCID ID: 0009-0004-6611-1149, Russian State Pedagogical University named after. A. I. Herzen, Department of Theory and History of Culture, Assistant