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CONTENTS

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Architecture

INBETWEEN HETEROTOPIA AND SIMULACRUM: VERNACULAR LANGUAGE OF COURTYARDS IN BANGLADESH'S ARCHITECTURE

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Abstract

Introduction: The courtyard was perceived by generations just like a religious act in Bengal delta. Even the community cohesion of the courtyard space was repeated and maintained in the township context, which neither belongs to agricultural nor working class but rather to educated elites with western zest. How has this unique feature been evolving and why is the appeal still the same today? Is the courtyard's permeability just the 'in-between space' or was it derived from the aspiration of philosophical legacy? **Methods:** The study uses a twofold method derived from solid-void relationships. Firstly, eastern and western philosophical discourses were compared, and the extensive literature review is presented. Secondly, historical evidence and logics behind the courtyard's position from micro to macro scale, from household to city formation is presented and analyzed in the philosophical context. **Results and discussion:** From a very complex lattice and layers related to architectural philosophy, two important figures of western world, Baudrillard and Foucault's ideas proved crucial to comprehend how an image of the courtyard remained constant and how it is empowered as a core space from the socio-cultural and functional views. The result affiliated western objectives and eastern subjectivity.

Keywords

Courtyard, Bengal architecture, conception of space, heterotopia and simulacrum.

Introduction

Chronological history of society depicts the changing pattern of human settlements. Embedded with commonplace behavior, such architecture created a language by combining a true approach and conceptualization. Better observation is always proportionate to better imagination. It is something related to observation of the surrounding watery landscape. Altogether, vernacular architecture is the best experiential essence of livelihood and psychological meanings. The vernacular courtyard germinated operative spaces to rationalize its presence. Solidity of any form built around or apart is called 'served spaces'. Although a lot of differences are evident in every single example of vernacularism, the architecture of Bengal never forgot its homesickness to this basic element, a deliberately 'left over' void which is full of activities, its mode undefined.

Literature Review

The three windows of Bengal

It's difficult to say what the fundamental style of Bengal architecture is, as the nation like the Bangladesh has been under several foreign influences for centuries. For nearly a millennium of Middle Eastern invasion, the architecture absorbed all the foreign elements according to its own zest. Bangladesh has only three remaining windows to retrospect and look through the architectonic past. Firstly, it is important to mention the archaeology of Buddhist Viharas, which are actually massive monastery-based Buddhist universities in some archaeological sites along with the oblong direction of holy Ganges. Those are river port-like settlements. Some examples of these archaeological sites are Paharpur, Mainamati and Mahastangarh built with Bengal's unique terracotta art, special brick modules and Buddhist architectural style, dating from the 7th to 13th centuries (Bandyopadhyay, 2016). The premises were unique and influential in the whole South-East Asia, and the temple architecture in the Indo-China belt wanted to achieve such artistic state. 'Mahasthangarh' means 'the most magnificent place on earth' (Ahmed, 2013).

Secondly, it includes medieval small-scale mosques and temple architecture of its own style. In fact, medieval Sultanate architecture was the first attempt to search for the own architectural style (Ahmed, 2006). However, the burning question comes: why could the traditional temples of India and Persian mosques not continue their rectitude pride in Bengal? The reason is that they either had a small scale or got fused with vernacular elements which were erected with local plasticity, Bengal bricks to resist this country's most venerable challenge – the climate. To be exact, floods and a 6-months monsoon season were the challenges.

And lastly, vernacular architecture in different rural contexts and topographies, which evolved to tackle all the climatic issues through a series of successful inventions over time, was an important component. Amongst all these, vernacular architecture is the most important for better understanding of this study, as it aims to be a fundamental one. The answer is always echoed from subaltern population with its responsive architecture. The construction technique and durability, planning and its inherent qualities to achieve the climatic responsiveness or cost effectiveness were proved well-judged to ensure comfort in this hot dry region. These were the solutions to confront the natural problems which evolved a common architectural soul, the courtyard. Again, the adages and maxims of the estimated time period that ranges from the 4th to 12th centuries were formulated by an ancient wise lady of Bengal, folk poet Khona, and are still popular among the agricultural societies of villages related to planning and proved contextual for this esteem (Ahmed and Ahmed, 2015). This again belongs to folklore culture which is synonymous to vernacularism, somewhat like architecture without an architect.

From the above discussions we can assume that architecture starts from nature, especially from the scale of a branched tree and the entrance approach of any natural cave. Nature was the first and foremost motivation of any architectural composition and fitted especially well in vernacular architecture, in its courtyards. When somebody is born, gets married or dies, the courtyard serves an assembly but of course the modes are of different environments. It's beyond any kind of definition and is multi-functional without the need of any built structures, it's a container but also its character is contained. Why does our traditional courtyard seem empty but full of activities? Community cohesion of courtyard spaces from Neolithic villages is still contextual for well-desired happiness. The stories of courtyards even brought life experiences from villages and transformed them into vibrant cozy spaces at every city dwelling. The traditional courtyard seems empty but full of activities: birth to death, marriage to quarrel. Stories of courtyards are a legacy: grandparents, as well as senior citizens, shape the realm of children there. This is also a legacy for education if somebody wants to practice craft or agriculture. Here masters meet their apprentices. Courts are educative by all means. Let us discuss the architectural order and its spatial quality of this feature.

The courtyard: the architecture of voids

In Bangladeshi villages, life has always been active through agro-based society. Architecture of this soil is essentially an expression of subaltern societies and constitutes the psychic of the amateur masons. Such agricultural society had plagiaristic approach in its lifestyle from dust and mud, which influenced its creation profoundly with self-effacing thatched huts made of mud, wood, hay, straw, clay, bamboo, etc. Vernacular architecture got remarkable variations, but a closer observation will reveal every individual hut gain its own inimitability. These houses have similar morphological characteristics as all the household works are arranged around an introverted central courtyard acting like the nucleolus of the house (Muktadir and Hasan, 1985). The length and width of the courtyard vary from minimum 10 feet to maximum 30 feet. A tree or a number of trees are one of the key parts of the courtyard's scale.

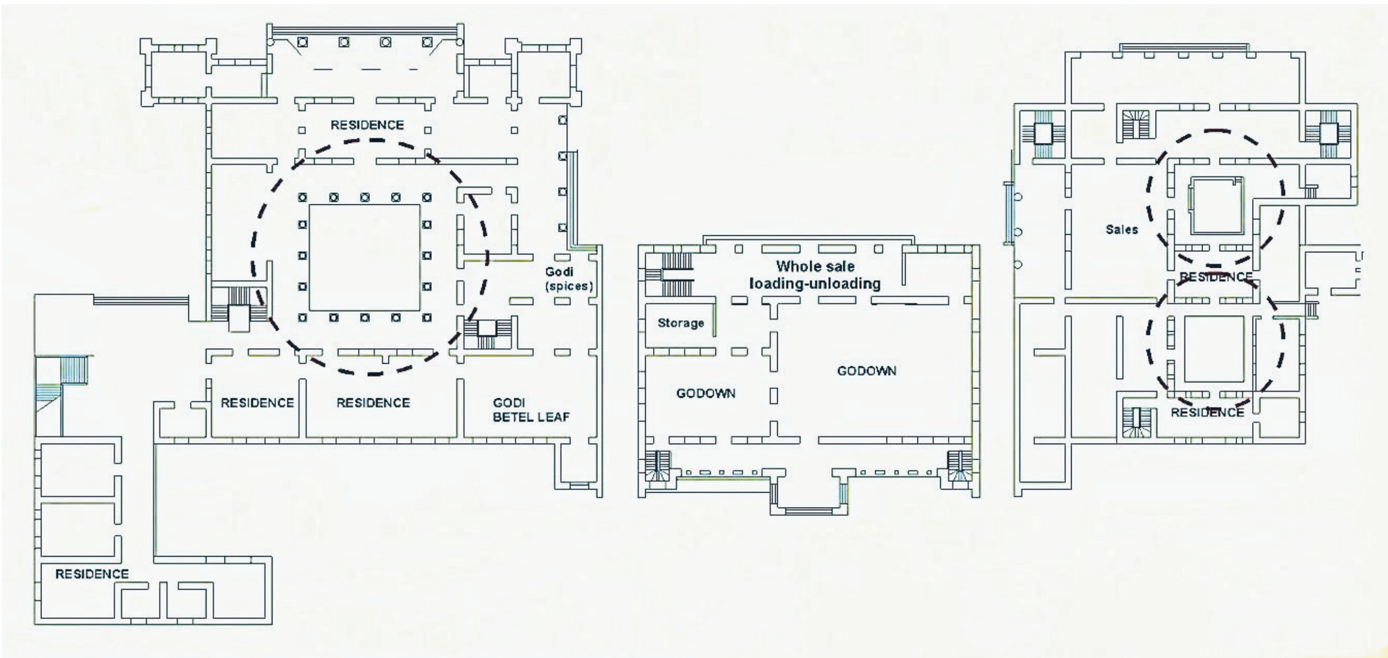

Figure 1: The traditional pattern of vernacular architecture, a cluster around a courtyard echoed in colonial architecture of Ruplal house, collected from bachelor thesis of Martuj Rasel, Bangladesh University, 07.02.2014

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Yet, new elements of daily experience, such as knowledge, value and behavior, are always allowed to be absorbed into certain attitudes that are deep within the psyche of inhabitants' collective consciousness and condition (Haque, 2009). Every detail comes from practical understanding; every planning decision comes from the user's need where the local wisdom lies.

Such indigenous architecture has a clear relationship to its collective religious behavior and norms. In fact, subaltern dwellings respect the lattice of intensity and contextually. Human behavior generated diverse forms in its spatial representation, which eventually converted indigenous public spaces like courtyards into an effective workstation (Nilufer, 2004). A homestead is an amalgamation of indoor and outdoor spaces (Kabir and Mallik, 2009). The scale of the semi-outdoor space needs to be very intimate and humane. A simple wall then gives an enclosure to the complex, gives the sense of privacy, accommodates the ancillary facilities and overall, defines an introvert sense of belongingness. Everything is possible for 'an open to sky' hollow in the planning, which can be used regardless of weather. The courtyards always accommodate the socio-cultural preferences of a particular community; even if they lose their function. Such image of a village also reflects the early settlement patterns of old Dhaka, sometimes referred to as 'township'. The openness of courtyards is also a good example of semi-public functions that successfully adapted to the congested urban fabric (Khan, 2006). Interestingly, it was possible to shift a whole house with boats with the benefit of water connectivity through canals even 100 years ago. They were erected around a desired court, in the newly owned land of the town context, a new place in a usual search for happiness.

As such architectural order has been developed from the daily needs of local people, the built environment and the pattern of spaces are the products of the daily interaction of dwellers with their neighbors. The degree of privacy is provided by the planning layout, so that it can maintain the socio-cultural balance of these rural communities. As the courtyard is surrounded by the enclosing wall, it also has privacy, so both men and women can use it simultaneously. It looks as an absolutely complete and matured plan with thoughtful insight. The most amazing feature is the rationality of space and clarity of the planning organization. The plans usually represent a square, where the focal organization is the courtyard. As the spaces are placed so carefully, it might seem that it is a craft where everything is perfect according to its needs (Hossain and Alam, 2012).

Conceptualization from Metaphysics

Conceptualizations of places differ among different people, and their meanings are not manifested in material space. Appreciating this concept is a vital precursor for understanding any vernacular settlement in the world. The specific meanings and conceptions of places can shape the core of any culture with a profound impact upon their daily behavior: both being and becoming (Rapoport, 1975) together with agro-artisan practices. The vernacular settlement can thus be seen as a system of spaces and places that are attuned to provide the settings and opportunities to sustain peaceful and fulfilled daily lives as much as for seeking and attaining a higher state of being in the future lives (Dayaratne, 2010).

From this point of view it can be seen that craftsmen and peasants in traditional Bangladeshi villages have very similar world views, indeed bound by an undeniable inter-dependency.

Regional philosophy is also common for every particular community with the same imposed cultural context. What does a court mean for the way of life? Let some philosophy get involved. According to Buddha; space is beyond any definition:

'This world is nil.'
Or
'To abandon is to get fulfillment.'

If the folk philosophy is not involved, then we might not do the right thing to judge the spirit of this land. Similarly, Lalon (1774–1890), the soul of this soil, said:

'খাঁচার ভিতর অচিন পাখি কেমনে আসে যায়'

It means: As a bird, a soul comes in and gets out of the 'cage' represented by a human body or structure (Shorkar, 1982).

In fact, it is necessary to introduce Lalon properly for this study. He was a mystic saint, songwriter, social reformer and thinker; the best folk poet, lord of the Bauls that Bengal has ever got. He became an icon of religious tolerance, his songs evoked many of the later poetic mastermind's philosophical thoughts including the first Asian Nobel Prize winner Rabindranath Tagore (Haque, 2017).

Figure 2: A 'Gosshaghar' for an unmarried lady in Sunamganj. Source: Author 2012-01-07

It is estimated that he had composed nearly 10,000 songs out of which it was possible to track down only 2,000 to 3,000; not in the written form but in the hearts of his numerous followers who could neither read nor write. His songs are also recognized as intangible UNESO heritage.

In architecture, light, water and wind can be represented as an idea of 'happiness' (Ahmed, 2017) and the architecture incorporating all these ideas could be thought of like a cage. A perforation in architecture may be one kind of expression for such freedom. Master mind Louis Kahn utilized this idea when he was bestowed with the duty to construct the Parliament building of Bangladesh, probably the most magnificent parliamentary building of the world and his architectural masterpiece (Curtis, 2012). His well-established theory of 'served and service' areas, their realization for people's needs and how to cater them from a court was inspirational for this master mind. Again, Lalon's thoughts and the first modern French philosopher Rene Descartes's 'Intuition' are the same in this regard, and we see the culmination of realism depicting a human in the center:

"I think, therefore I exist".

Later, Freudian idea indicated that subconsciousness of human mind was freedom. (Perforation). However, the challenge is that only architects need to create the reality, while all artists got the rights to create the false or illusions.

Let us now go back to the period when the human civilization invented fire and its associated spaces from where this study started its discussion. It could be identifiable now from all other cultures, private and public, family and social, leisure and work, that such classification indicates a hidden presence of sacred spaces. Primitive society is the best example of crisis and its space according to Michel Foucault is called heterotopia. Spaces of heterotopia give the essence of 'another space' within a space (Foucault, 1997) and are really powerful. Human mind is in elsewhere if it comes to contact with these spaces. Some opposite heterotopias are temporal and connected with time. They are accessible if arranged for any public event, but responsive only in the particular season. Heterotopias develop a system of opening and closing as they are not freely accessible. The function plays the vital role to create illusion, but also ensures social interactions (Foucault, 1984). For example, trade fair ground in the winter landscape of Hoar areas and the 'Gossha ghar' or room of anger where an unmarried girl is given a peer to wait for her marriage after the next monsoon.

As an important western concept-binder, this study wants to introduce Mitchell Foucault. He considers an axiom that states that 'Liberty is practice' and concludes that architecture cannot be fundamentally oppressive either. It is also agreeable to some extent that 'the architect has no control.' Again, a perfectly elaborated set of lines that any architect creates in their drawings will not materialize with the same level of perfection than he has imagined initially (Ahmed, 2016). A simple example of an architectural element could be the door, which is a device to any functional allowance, from the impenetrable state of being closed to the porous state of being open for entry (Foucault, 1982). However, courtyards are open, but again one needs to seek permission there, with scaling or narrowing the pave or by vegetation, which creates an environment to mound one's psychology. It could be referred to as a planning diagram, as every human being is an architect from their inert. Foucault reads this architectural diagram through a two-dimensional form of representation, which expresses various forces created by its lines. If the courtyard is the meeting point of such lines, it does not show the influence, rather defines the edges. Again it avoids all those influences, as it wants to remain independent from any kind of alignment, rather invisible diagonal forces are predominant for the connecting purpose. This is the basic idea of Foucault's interest, known as cartography. It is the activity that considers a given situation within the reality and elaborates diagrammatic representation.

'It is a machine that is almost blind and mute, even though it makes others see and speak.'

Moreover, Foucault focused his interest on human science, which is closely connected with the society, psychology, sociology, economics, linguistics and medicine (Foucault, 1979). Above all, his 'so called' power of spaces is very contextual for the courtyard study. It is the court of law for judgment from the very early period of human's social settlements. It is also the court of one's social status: whether you are from agricultural or craft-based society, it always tends to reflect its owner's economic character. For linguistics, the gathering of Bauls with a central fireplace could be the best example. The penetration of the sacred herb like Tulsi (Ocimum tenuiflorum) in a Hindu courtyard is an example of herbal medicine. The courtyard is the symbol of all basic needs as well as the fundamental space for every aspect in exercising the power.

And, most importantly, courtyards are also a flexible example of 'Panopticon' (Foucault, 1995). They are visible and audible from one's known realm and center of a simple controlled indigenous and initial society, but, of course, a successful example for the degree of observation and freedom. It is not a prison, but is the society behind courtyards with religious rituals and social norms not an invisible prison? What one cannot do in the courtyard cannot be done in public places either. The imperceptible 'prison' starts from educative courtyards.

Even to assume the sun clock, the courtyard tells the reality about the time and rural people's experience of time, and this knowledge is well adjusted there. This practice led ancient people to be caught up in time. And this being 'caught up' is always poetic. Open-to-sky spaces are thus divine from the view point of the architect Charles Correa and one can relate its spirit with spirituality. According to Heidegger, humans, thus, are dwelling poetically (El-Bizri, 2015). The courtyard is the rhythm of that poetry.

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The anti-courtyard

Does this courtyard only convey the core idea of all our built forms? It may not always be true. In another context, 'Mer' in a haphazard but intimate scale from the civic perspective of old Dhaka is also an exemplification of the 'beyond the ownership' concept. It is a civic practice where an elevated spacious veranda without any fencing is kept for serving the purpose for public resting and childish activity in front of a roadside private home. It is prominent that the architecture of freedom and sharing in an intimate cluster was never omitted. This vernacularism got its root in water, not by means of defending, but to adapt to a smaller floating scale. Let's discuss one and the only available example in this region.

In the country with more than its fair share of cultural diversity, the Bede people are not only distinctive in their traditional lifestyle but also in their religious, social and cultural patterns. The estimated 1 million river gypsies or nomads of Bengal, the name derived from the Hindu cast Baidda, means doctors or people of profound knowledge in medicine. They are descendants of 'Montong' tribe of Myanmar. They are highly regarded in our folk culture,

Figure 3: Mer, full of joys and activities regardless of ownership. The photograph from the PhD thesis of Iftekhar Ahmed, Honkong, Street house interface: Some basic elements of Old Dhaka Urbanism. Page 143 (2012)-01

as they charmed snakes, performed magic, trained monkeys, and practiced traditional medicine and spiritual healing (Dalton, 1978). The Bede people used to live in boats, they travelled in groups from one village to another for 10 months every year, stopped in almost 90 villages on their way and seldom stayed for more than 3-4 days in one spot. They rested a couple of winter months, settled for rest, marriage, and other social functions, when all the rivers had already dried out. These are semi-tubular shaped tents, covered with bamboo fences. The Bede people's distinctive socio-cultural pattern at their boat's hollow follows the similar sequence of courts, but they float. The floating courts are heterogeneity that helps to continue their dreams.

There are 65 prominent areas in Bangladesh where Bedes come for yearly gathering. Since Bedes have to live either in small boats or tents, the average per capita living space enjoyed by them is much less than city's slum people who suit in a 10 square feet accommodation (Maksud, 2006).

Figure 4: Bede's boat dwelling or series of courtyards. Available at (https://cafedissensus.files.wordpress.com/2016/07/2-bede.jpg?w=217) accessed on 11. 07. 2017 Courtesy: Carmen Brandt, Café Dissensus, 2016-07-19

Figure 5: An educative courtyard of weavers in Tarabo Jamdani village, Narayanganj. Source: Author 2017-03-26

Finding and Analysis

After the careful literature review, this study shapes the findings according to Baudrillard's vision. As an opponent of Foucault's post structuralism, Baudrillard is his antagonist, a worshiper of hyper reality. His hyperrealism depends on the 'image making', which he successfully called simulacrum. This may include perception, religious imagery, natural phenomena, creative engagement and spiritual rendezvous of our experienced environment along with psychology. According to Baudrillard's idea, simulation is an active process of replacement of the real. Simulation threatens the difference between the 'true' and the 'false'; the 'real' and the 'imaginary'. In its advance stage it turns into hyper reality, which is in fact the generation of symbols of the real without origin in reality. Simulation refers to a process in motion, whereas simulacrum (plural simulacra) refers to a more static image.

Now, there are 4 orders of such 'image making' according to Baudrillard:

1. Faithful: The image reflects a profound reality. This is always present in traditional and social hierarchy. It is a direct copy of reality. For example, classical paintings and sculptures in Europe.
2. Perversion: Masks and perverts of any profound reality. This is the aesthetical tool to pervert the basic spatial reality.
3. Pretense: the absence of profound reality. Disneyland is an example.
4. Pure: Own pure simulacrum. Substituting signs of the real for the real itself. Here, representation comes from simulation but later it becomes a sign of simulacrum. It is the ultimate matrix, the known world is an illusion now.

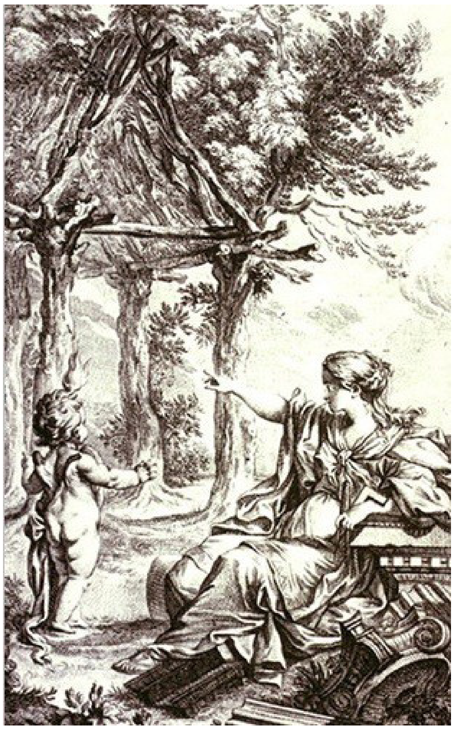

Figure 6: Marc-Antoine-Laugier: the primitive hut, 1753

Buadrillard wanted to focus on the symbolic acts of image making. In his four Objective Value Systems mentioned above, the first three values are direct simulations of nature.

At the Faithful stage, architecture depends on the architect's imagination and observation, proportionate to each other. For example, cave architecture in Lomus Rishi cave in Bihar dated from the 3rd century BC is the direct representation of primitive caves. Marc-Antoine L'Augier's painting in his book 'Essay on architecture' from 1755 has already shown us that architecture starts from nature. Vernacular architecture around the world tends to imitate this reflection sill.

Figure 7: Hindu courtyard's identity is Tulsi tree

Perversion is the second stage of simulation. He puts 'symbolic value' in the third place where he describes any object in relation to another subject. A higher idea takes a real object as a vehicle and also symbolizes the reality. The second stage has a lot of examples. For example, fire representing spirit in Baul's homestead, an icon like Tulsi tree in Hindu court are the classical examples of simulacrum of this stage. Once Loius I Kahn asked the brick what it wanted to be, and the answer was an arch. It was in his mind, in his vision, the brick was just a medium to express it. Again, the modernist period in architecture regarded ornamentation as crime, it shows how basic reality can be absent and presented by simple, basic and architectonic shapes and platonic solids or volumes. Again, it has some 'sign value' which indicates the system of objects. For instance, the social status has always been perfectly represented in Bengal's courtyards. Whether they belong to craftsmen or aristocrats, the activity flourishes its space character. In fact this is the border line that all architects deal with; this stage is the limit of the image making and representation option.

The third stage is also present in the courtyard, but how? Different sorts of amusement installations and our imagination convert us into desired superheroes and we have different roles playing with the peers - everyone can make any courtyard into a mini Disneyland. It could also be educative.

Architecture is a supreme medium of visual culture, no doubt. It naturally reflects any individual's perception of reality; even the creator (architect) is a part of it.

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'Singularity' can be considered as an object and there is nothing homogeneous or global. Regardless of the region, cultural background, time and people, the courtyard is universal, but again it is local. The courtyard contains different simulations, which reflect topography, socio-cultural and even political contexts. However, it is a real multifunctional void which is not definable. It fulfills the first three stages of simulacrum as this study finds.

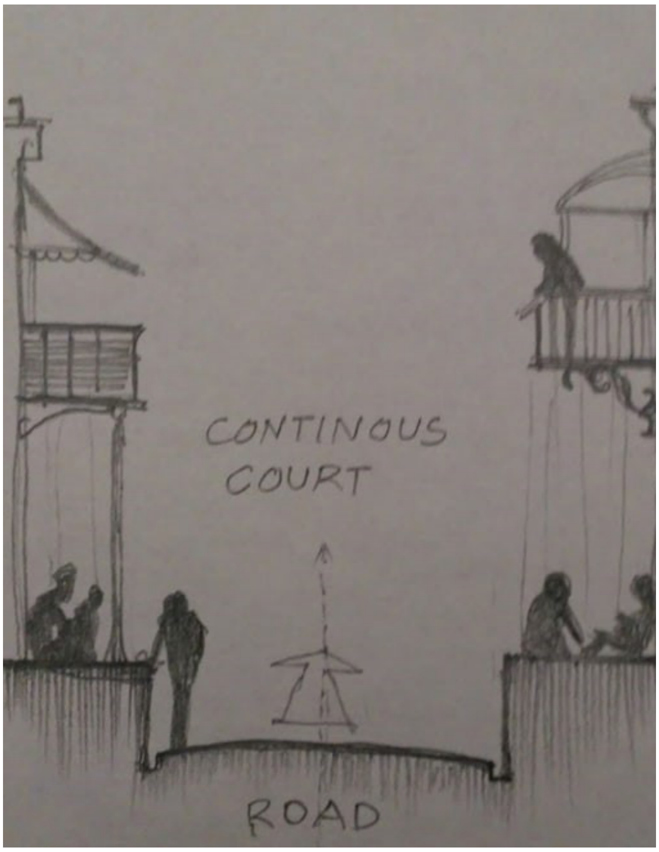

Figure 8: Chat of Roak and Streetscape created the 'sense of continuous courtyard' in old Dhaka

Just like 'hope' or 'dream' in the theory of Foucault's heterotopia, a boat of Bede community could be seen as an exception but not aloof from courtyard's uniformity. Similarly, Mer conception of old Dhaka creates courtyard like a sense from a streetscape if offered on both sides of a narrow road. Such street could be a continuous courtyard. The landscape is much more powerful than architecture, and the courtyard is the reminding character of that landscape, where architecture should return to a form of archaeology. In modern and contemporary architectural practices, prominent architects of Bangladesh have never overlooked its presence in their works but rather promoted courtyards in the design style and site context.

Conclusion

Western and Eastern philosophies might come to the same point to define what the meaning of nothingness of any undefined space is, which is actually this study's core conceptualization. Mystic eastern philosophies like to nullify and void in the built form and circulation around a

Figure 9: Pathsala (school) and Hukkah craft (tobacco holder) courtyards in 1860 at East Bengal showing social status with occupation pattern of homeowner. Source: British Library, London

well established by their functional organization Buddhist architecture. For subaltern people this was their court, simply a void of nil but responsive to their basic needs, as Foucault identified. This is as ancient as the first spark of fire. Heterotopia exists, but it is merely identifiable from the primitive concepts and changes of seasons over the given topography, it plays the vital role to feel the poetic essences of phenomenology. There is a passive control in nature, and humans also do know how to educate themselves, which starts from the most primitive institution like the family, while classroom is a social invisible prison of educative courts. Foolish architects always trap themselves into an 'optical prison' where the architecture does create or shape architects, but architects cannot create architecture.

In fact, cozy spaces from the very early childhood of a person are important for their identical spatial quality. Terraces, pergolas, verandas, open-to-sky courts, semi-outdoor spaces are such sort of spaces that have a more meaningful origination in vernacular architecture than any designed one. Biennial characters have great impact over those micro-climate spaces both in lateral and frontal elevations. Structural systems and fenestrations, of course, for the design consideration of a particular climate shaped the housing with those beautiful and happy ‘trivial’ spaces. Neolithic villages differed from region to region as the topography differs. It reveals the issue of high population density in Bangladesh. Flourishing of such villages since 2500 BC was the key reason along with the natural water networking. Thus, the community cohesion was still maintained in the organic town planning with water connectivity. And the most evolutionary invention of humans, the fire, was discussed at the very beginning of this study as a witness of the courtyard’s unforeseen role in different cultures. To recapitulate, it is distinct now that our ‘courtyard spaces’ are aspirations based on our agricultural legacy considering something ‘in-between’ in overall space. Clustered ‘in-between’ spaces of such vernacular architecture altogether created ancient villages. And again, connecting all villages along waterways shaped the ancient civilizations in this subcontinent and in other parts of the tropics where it was possible for humans to be well suited to the tropical belt of earth. Such ‘happy courtyard series’ resulted in villages. These villages were the first to be evolved for the succession of ancient human civilizations.

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MODERN TRANSLUCENT ENCLOSURES IN ARCHITECTURE

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Abstract

Introduction: The study addresses different types of translucent enclosures currently used in architecture and construction. Modern classifications of such structures and their disadvantages are described. The authors propose a classification combining and systematizing all existing types of translucent structures. They also provide examples of architectural objects where such solutions are implemented. **Purpose of the study:** The study aims to systematize and update classifications of different types of translucent enclosures, determine their role in the formation of architecture and the provision of an interaction between the internal and external space, to identify the form-generating potential of such structures. **Methods:** The authors applied a systemic, multi-factor approach to the matter under consideration, reviewed and systematized scientific as well as architectural-and-design sources to analyze buildings designed with account for the use of translucent facade structures. They describe all types of such structures and provide a table with projects of well-known architects and corresponding drawings where the described types of facade systems are used. **Results:** The authors identified the form-generating potential of glass structures, analyzed the role of translucent enclosures in the formation of architecture and the provision of an interaction between the internal and external space, and developed a new classification for modern types of translucent facades with account for architectural-and-design characteristics.

Keywords
Translucent enclosures, light, glass, facade, facade glazing system, classification.

Introduction

Glazed facades have become an important element of modern architecture. The amount of light penetrating a building through translucent structures is an essential criterion for the assessment of space quality. Therefore, to create harmonious architecture, it is required to study ways of working with light. Besides, such studies shall be comprehensive in nature (Fedorov et al., 2015). Facade glazing not only has particular light-transmitting properties but provides a spatial layout that defines the appearance of a modern building. Being a tool of aesthetic transformation, the glass transforms not only the urban environment but the interior environment as well: visually, space becomes lighter, the contact with nature is achieved, an artistic and compositional play of light and shadow occurs.

When developing translucent facade solutions, due to high aesthetic potential, functional significance and variety of design solutions, architects shall be familiar with the full range of design variations, their advantages and capabilities. Facades with translucent glazing significantly affect the building appearance and architecture. The exceptional importance of glass as a material and translucent facades as a design solution can be explained by specific properties of glass distinguishing it from other materials. Such properties include the following: transparency, reflectance, geometric clarity, decorativeness (decorative capabilities) (Fedorov, 2007; Fedorov and Lazina, 2018). Due to the efficient use of these properties, it is possible to solve all kinds of architectural and artistic tasks and develop various conceptual designs.

Through the use of the transparency of external structures, the interaction between the interior of a building and its exterior, as well as people outside, can be ensured. A glazed surface allows us to “look inside”. It symbolizes the “openness” of an establishment / “transparency” of processes occurring inside or draws the attention of people outside to the interior design. A principle of communion with nature is implemented.

As for reflectance, any glass has such a property. The degree of reflectance, which is a defining characteristic, ranges from the minimum to the maximum. The reflectance property allows buildings to “merge” with the environment as the landscape and daylight depending on time and weather are reflected by glazed surfaces. Using this property, it is possible to achieve interesting artistic and compositional effects when glazed surfaces reflect various elements and parts of a facility.

Geometric clarity can provide extremely smooth surfaces, absolutely flat lines and faces of facade elements, or geometric perfection of doubly curved

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shapes. These properties and features of glass, allowing us to sculpt the facade composition and individual details, as well as two-dimensional capabilities of the material, make it possible to create a unique building envelope using modern translucent enclosures and ensure geometric clarity of lines and faces.

Decorative characteristics involve the possibilities of creating artistic translucent compositions, colored and tinted glasses, or glass reliefs, print various images on glass, etc. Using these, it is possible to give architecture both an artistic and conceptual verbal meaning. Among other things, space is enriched, architecture becomes more complex, expression of an artistic form intensifies due to the use of more complex lighting configurations (coloring and refraction of the rays of natural light) (Fedorov and Lazina, 2018).

As there is a variety of visual and conceptual characteristics, and translucent enclosures have a high form-generating potential, it becomes necessary to provide a classification of translucent structures, convenient for architects.

Existing classifications of current types and methods of glazing (based on different sources) are presented below.

State Standard GOST 33079-2014 “Translucent enclosing structures. Classification. Terms and definitions” offers the following classification (Table 1):

Table 1. Classification of translucent facade structures

Classification criteria	Types
1. Location of the structure:	– suspended structure; – integrated structure; – combined structure.
2. Type of the load-bearing frame:	– mullion-transom structure; – modular structure; – post and beam structure; – cable structure; – frameless structure; – combined structure.
3. Material of the frame:	– steel frame; – aluminum alloy frame; – timber frame; – laminated glass frame; – plastic frame; – combined frame.
4. Type of translucent cladding attachment:	– mechanical attachment with external pressure plates along all or several cladding edges; – mechanical attachment with internal pressure plates along all or several cladding edges; – mechanical attachment with external/internal point fixations in the form of clamps along all or several cladding edges; – mechanical attachment with external/internal point fixations in the form of bolted bearings; – glued (adhesive) attachment along all edges of translucent cladding; – glued (adhesive) attachment along several edges of translucent cladding; – combined attachment including two or more types of attachment.
5. Availability of mechanical attachment elements projecting from the glazing plane:	– with visible attachment elements; – without visible attachment elements; – combined.
6. Type of translucent cladding:	– plate glass; – laminated glass; – glass units; – profiled construction glass; – translucent plastic products.

The VEKA company, a leader in the design and manufacturing of window and door systems made of high-quality plastic, suggests another classification. It distinguishes several groups by the following indicators: total area of glazed surfaces on the facade of a building; design solution and mechanism of load resistance; translucent elements of glazing used in vertical light openings in external walls. These groups include:

– Window units used in small light openings in walls.

– Ribbon glazing along the length of a facade, covering the height of one story, with a non-transparent window apron and header.

– Panoramic glazing, covering the floor-to-floor height of one story.

– Suspended translucent facade structures.

– Translucent structures for the glazing of projecting and recessed balconies (Architectural solutions for translucent structures made of VEKA profile systems,2011).

In the book "Buildings and structures with translucent facades and roofs. Theoretical foundations for the design of translucent structures", the Institute of Construction and Architecture of the Moscow State University of Civil Engineering distinguishes three groups of suspended translucent facades by their design and method of construction.

– mullion-transom systems;

– unitized (modular) facades;

– spider systems.

Mullion-transom and modular facades are divided into the following subgroups (by method of translucent glazing (glass unit) attachment to the elements of a profile system):

– standard (with the mechanical attachment of glass units);

– structural (with a bonded glass unit) (Boriskina, 2012).

Based on the analysis of these classifications, the following can be concluded: the classification suggested in the state standard is rather complex and disorganized, and it actually presents several classifications by different criteria (without any clear idea of glazing options); for convenience, the classifications suggested by the Institute of Construction and Architecture of the Moscow State University of Civil Engineering and the VEKA company are simplified to the maximum extent but they do not cover all types and methods of glazing used nowadays. The classification suggested by the VEKA company has no unified criterion to distinguish between types of glazing. It is based on various aspects: from architectural and geometric to heat-engineering characteristics.

Tasks and methods

The tasks of the study are the following:

– to analyze various systems of translucent enclosures (based on national and international experience);

– to identify the form-generating potential for various types of such facades;

– to systematize data and develop an updated classification for translucent enclosures;

– to determine aspects of providing an interaction between the external and internal environment with the use of translucent enclosures based on their structural and technical specifications as well as factors of the external environment.

The methodological basis of the study is a comprehensive approach including:

– analysis of architectural objects designed with account for the use of translucent facade structures;

– comparative analysis of different approaches to the design of architectural space;

– analysis of the relevant scientific and regulatory literature;

– comparative analysis of principles, tools, and methods of the design of building with translucent enclosures;

– classification of the identified types of glazing;

– graphical and analytical analysis of translucent facade structures.

Results and discussion

With a view to the disadvantages of the existing classifications described above, in their work titled "Energy efficiency of buildings and structures with translucent constructions", Fedorov and Lazina suggested a new classification for translucent facade structures (Figure 1).

Types of facade glazing			
Glazing using a mullion-transom system a) Attachment to the frame - mullion-transom glazing; - mullion glazing; - transom glazing. b) Availability and size of pressure plates - glazing with pressure plates; - glazing without pressure plates.	Profile glazing - wooden profiles; - aluminum profiles; - plastic profiles; - composite material profiles.	Point-fixed glazing (planar glazing) - attachment directly to enclosures; - attachment using plane structures; - attachment using spatial structures.	Glazing with the use of structural glass - glass brick; - U glass; - full glazing with laminated glass (adhesive base).
Combined glazing			

Figure 1. Types of facade glazing.

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The suggested classification has the following advantages and distinctions:

– it covers all types of facade glazing used nowadays, combining existing developments in the area, considering modern trends of scientific progress and new manufacturing capabilities;

– it introduces a new type of combined glazing, taking into account the possibility of using complex combinations of various design solutions in a facade;

– it differentiates types of facade glazing mainly by design, which determines the appearance of facades to a great extent (therefore, it is important for architects to understand the specifics of this feature);

– it allows for changes and modifications (it is possible to update and supplement data with a view to technological development and constant search for new trends in facade glazing).

The first type of facade glazing – glazing using a mullion-transom system – involves translucent facades where mullions and transoms are load-bearing elements. Mullions and transoms (i.e. a frame) ensure the attachment of the structure to load-bearing members of a building. A glass unit is attached to the load-bearing frame using pressure plates, above which decorative cover caps are installed. As a consequence, the translucent plane on a facade is divided into individual parts. Combining joints of mullions and transoms, it is possible to integrate tilt-and-turn structures and entrance units into a facade, create a pyramidal structure on the top of a building, assemble curved glazing. Vertical and horizontal load-bearing profiles of the mullion-transom system can be joined in several ways. Therefore, it is possible to choose a joint depending on a particular facade.

Mullion or transom attachment is also possible. In this case, the interaction between the internal and external space strengthens as the area of the non-transparent part reduces. The scope of view of the external space expands for those located inside. Outside, typical dynamics is observed (stylistic and visual elements directing upwards and sideways).

With the appearance of extra-strong silicone sealants, it became possible to glaze facades with no (or with partial) mechanical attachment of glass (a glass unit) to the load-bearing frame. Such sealants are characterized by excellent adhesive properties. They are UV resistant and can withstand rapid changes in temperature. If no mechanical attachment of translucent glazing is provided, there is no need for pressure plates. The space between glass units is hermetically filled from outside: a structural joint is formed (that is why in many sources such glazing is called “structural glazing” (Smirnov, 2005)). In case of partial mechanical attachment (combined, with the use of a sealant), narrow and almost invisible pressure plates are used, which simulate the structural joint (Alutech Group. ALT F50 mullion-transom facade. Available at: http://www.alutech-group.com/product/profiles/f50/stoechno-rigelny-fasad/; Schittich et al., 1999). Through the use of such glazing, a building is seen as a single piece. Visually, it becomes light and smooth (Table 1).

If two-pane windows or single plate glasses are used, the mullion-transom glazing system is considered “cold”. It is applied in warm-climate regions. In a cold climate, three- and four-pane windows with an inert gas between the panes (“warm” glazing) are used (Fedorov and Lazina).

Profiled glazing in translucent facades is represented by floor-to-ceiling window systems. Profiles used in such glazing can be aluminum, wooden, or plastic.

Modern wooden windows are a synthesis of the latest technologies and eco-friendly materials, which make it possible to produce non-toxic reliable structures with beautiful appearance. Wooden window crossbars are usually used indoor under dry, normal, or wet conditions. The cost of wooden windows is higher than the cost of plastic ones as wood requires long-term drying, thorough treatment with a preservative, and moisture protection. Duly treated wood is a durable and reliable material. Among the main advantages of wooden profile systems, the following can be distinguished: environmental friendliness and better heat-engineering performance (as compared with windows with plastic and metal profiles).

The concept of manufacturing and using modern plastic profiles reduces to a compromise between the cost and high quality of a product. Choosing a plastic profile, it is necessary to pay attention to the frame sealing. The frame shall have two sealing strips. Otherwise, condensate will accumulate under the frame, deteriorating the insulation and creating a perfect environment for bacteria and mold to grow. Hollow sections in a profile improve its heat-insulation properties. Due to its weather-proof properties, PVC does not absorb moisture, swell, decay, or crack.

Aluminum windows are characterized by high strength, a reliable structure, and long service life. They are often used in public facilities and residential buildings. Like other metals, aluminum is non-combustible, can withstand rapid changes in temperature and heavy static loads. Moreover, it is lightweight, so it is a perfect choice for window manufacturing. Modern technologies of window frame manufacturing from aluminum profiles, significantly reducing heat transfer in the material, achieved particular progress. That is why recently aluminum windows have become popular in individual housing construction, glazing of recessed balconies and structural additions (Table 1).

Such glazing is limited by height as it is mounted between floor slabs. Thus, we see a clear floor-by-floor division of glazed facade parts from outside.

The principle of point-fixed (planar) glazing is in the following: glass is attached to a spider – a spatial bracket made of high-alloy steel – through drilled holes (Schittich et al., 1999). The spider bracket is fixed to frame posts, transmitting the load to them. The load-bearing structure of such glazing is represented by plane and spatial systems (Smirnov, 2004). Plane load-bearing systems include steel tube trusses, vertical posts, rod and cable trusses, vertically extended ropes. Spider glazing with the use of ropes is one of the most attractive systems. However, due to complex structural analysis and assembly, it is the most expensive as well. Spatial systems include pyramidal strut structures and grids. Finally, attachment of a suspended glazed facade directly to enclosures (to a wall) is the simplest way of attaching translucent material with fasteners. The lack of load-bearing frames between glass panels is the main distinction of planar glazing, and the possibility to highlight a unique building style is its main advantage (Table 1).

Using a spider structure, it is possible to mount glazing by joining panels at any required angle. In this case, the load is uniformly distributed by all fixation points. Planar glazing is not limited by height and has an advantage over two other types of facade glazing: fixation points of translucent glazing make a structure lighter and ensure a smooth interaction between the internal and external space. It is mainly used for "cold" facade glazing or as an additional facade layer for decorative and heat-insulation purposes.

Glazing with the use of structural glass includes glass brick, U glass, and full glazing with laminated glass (adhesive base).

Glass brick is used in civil buildings to form translucent openings without crossbars (e.g. in walls of a stairway). Window openings filled with glass bricks are characterized by soundproofing, durability, fire-resistance, good illuminating properties, and soft diffused lighting. Glass brick glazing also ensures tight enclosures, improves resistance to heat transfer, and reduces the penetrating heat radiation. Moreover, glass brick is a hygienic material that requires less costs for maintenance. To compensate for temperature deformations between the glass brick enclosure and the wall, gaps filled with elastic materials are provided, and reveals are plastered (Lazarev, 2009).

U glass represents U-shaped glass beams with a thickness of 6 or 7 mm and a length up to 7 m. They are used to construct internal and external light-diffusing glass partitions, facade enclosures. The element structure consists of a visible beam part and side plates. Glazing can be single, double, or triple. In case of double glazing, beams are mounted in pairs, with their side plates directed towards each other. Together they form a rectangular tube, or a glass block (Pilkington U glass. Available at: http://www.slate.ru/catalog/pilkington).

With the frosted glass (in glass brick and U glass), it is possible to "barricade" against the external world, preventing glances inside. Soft diffusing beams of light still pass through the glazing.

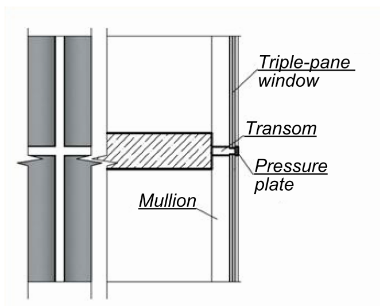
Full glazing with laminated glass (adhesive base) is a facade structure where just one material (triplex (laminated glass)) is used to form enclosing glass units and vertical load-bearing stiffeners with an adhesive base. Such glazing is characterized by the lack of other materials and fasteners, which makes it possible to look through the glass easily. Buildings with such glazing immediately catch the eye. It is as if they are weightless and transparent (Table 1).

Conclusion

The active implementation of modern translucent enclosures in architecture is conditioned both by their form-generating potential and by the provision of an interaction between the external and internal space. Sometimes, the external environment represents a determining factor in construction. The beauty of the waking spring nature, clear summer sky with the bright sun shining, the riot of autumn colors, and winter monochrome landscapes are the reasons for glazing in private residential buildings. People tend to commune with nature in the urban environment, increasing areas of transparent structures, providing visual access to the sky, natural lighting and the urban structure in general.

The structures described above can be presented in the form of a systematic table.

Table 1. Types of facade glazing

Types of facade glazing	Drawing	Examples in architecture
Glazing using a mullion-transom system a) Attachment to the frame – mullion-transom glazing; (Example in architecture: Mercury City Tower, Moscow, Russia. Architects: F. Williams, M. Posokhin, G. Sirota)		

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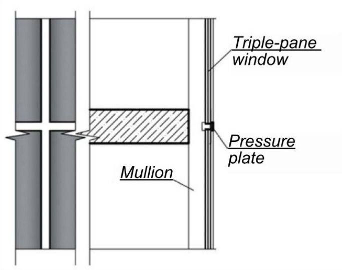
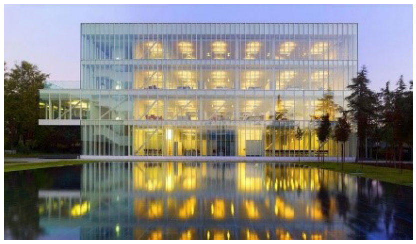
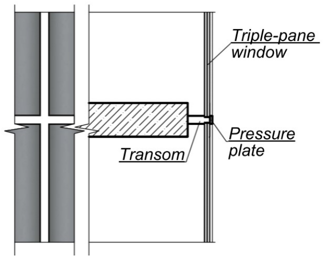
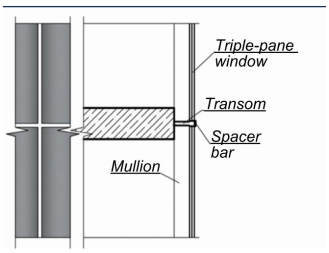
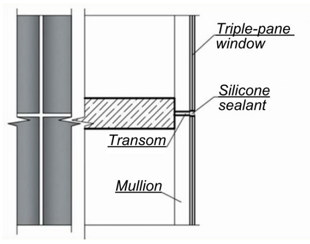
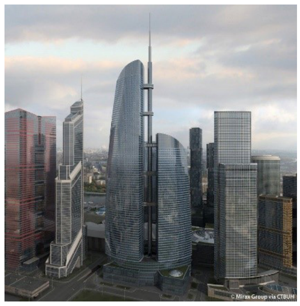
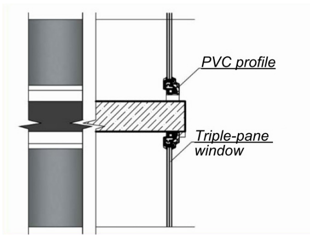
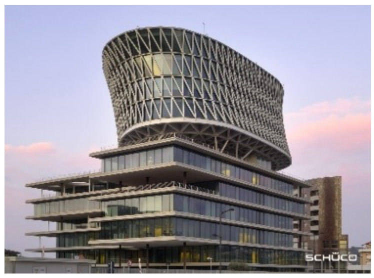
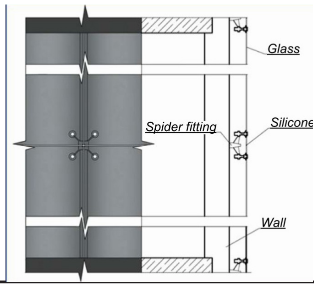
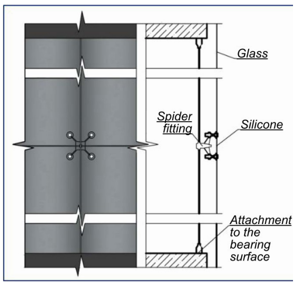
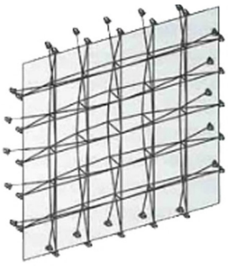
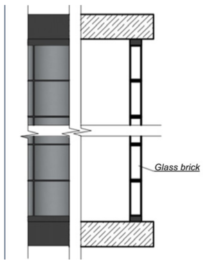
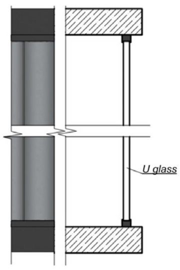
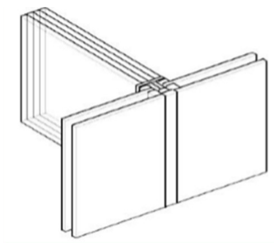
– mullion glazing; (Example in architecture: Çimtaş Administrative Offices, Bursa, Turkey. Architect: Mimarlar ve Han Tümertekin)	 	
– transom glazing; (Example in architecture: Saint Petersburg Plaza business complex, Saint Petersburg, Russia. Architects: E. Gerasimov, S. Choban)	 	
b) Availability of pressure plates – glazing with pressure plates; (Example in architecture: GlaxoSmithKline Canadian Head Office, Quebec, Canada. Architects: Coarchitecture)	 	
– glazing without pressure plates. (Example in architecture: Federation Tower. Architects: S. Choban, P. Shveger)	 	
Profile glazing – wooden profiles; – aluminum profiles; – plastic profiles. (Example in architecture: Polo Direzionale De Cecco business center, Pescara, Italy. Architect: M. Fuksas)	 	

Point-fixed glazing (planar glazing) – attachment directly to enclosures; (Example in architecture: National Library of Belarus. Architects: M. Vinogradov, V. Kramarenko)		
– attachment using plane structures; (Example in architecture: Sandro Penna Library, Perugia, Italy. Architect: Italo Rota)		
– attachment using spatial structures. (Example in architecture: Berlin Central Train Station, Germany. Architects: Gerkan, Marg & Partners)		
Glazing with the use of structural glass – glass brick; (Example in architecture: House of Glass. Architects: P. Chareau, B. Bijvoet, L. Dalbet)		
– U glass; (Example in architecture: glass building on the bank of the Mississippi River, Louisiana, USA. Architects: Trahan Architects)		
– full glazing with laminated glass (adhesive base). (Example in architecture: Helsinki Central Library Oodi, Finland. Architects: ALA Architects)		

Due to its advantages listed as well as a wide range of design solutions and visual-and-decorative solutions, glass is one of the most demanded materials in construction. In terms of energy-efficient construction, these advantages are especially relevant. Using those, it is possible to ensure maximum energy efficiency, reduce heat losses and energy costs, preserve and improve visual characteristics (Great Glass Buildings; Fedorov, 2016). As long as the daylight lasts, it is light in buildings with glazed facades. This makes it possible to save energy and enjoy natural lighting (Fedorov et al., 2017).

It is hard to imagine modern architecture without glass surfaces. It first of all concerns business centers, industrial and commercial structures. Their gleaming facades and display windows are presentable and impressive. There are many unique buildings and structures in the world (Lonescu et al., 2015) we shall still be able to enjoy even from indoors. Translucent structures ensure visual access to the sky, natural lighting, the urban structure, and the beauty of the landscape.

Each of the described types of glazing has its own set of characteristics and scope of application. Knowledge of existing possibilities and specifics of using such structures is a key to the solution of architectural tasks related to lighting, the microclimate in buildings, their energy-efficiency indicators, and visual quality (decorative characteristics, aesthetics, and architectural composition). New types and methods of glass manufacturing constantly emerge, offering architects great opportunities, mainly in terms of expressiveness. That is why it is so important to choose the type of facade glazing based on the idea of the visual effect of a future building or structure.

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СОВРЕМЕННЫЕ ВИТРАЖНЫЕ ОГРАЖДАЮЩИЕ КОНСТРУКЦИИ В АРХИТЕКТУРЕ

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Аннотация

Введение. В исследовании изучены, использующиеся на данный момент в архитектуре и строительстве, виды светопрозрачных ограждающих конструкций. Приводятся современные классификации таких конструкций и обозначаются их недостатки. К внедрению предлагается авторская классификация, объединяющая и систематизирующая существующие на сегодняшний день различные виды витражных светопрозрачных конструкций. Приводятся примеры объектов с соответствующими решениями. **Цель исследования.** Систематизация и актуализация классификации витражных ограждающих конструкций разных типов, определение их роли и места в формировании архитектуры зданий, обеспечении взаимосвязи внешней и внутренней среды, выявление формообразующего потенциала таких конструкций. **Методы.** Системный многофакторный подход к исследуемому вопросу, изучение и систематизация научных, архитектурно - проектных источников с целью анализа сооружений, спроектированных с учетом использования светопрозрачных фасадных конструкций. Приведено описание каждого типа конструкции и в табличной форме представлены графические схемы и проекты известных архитекторов, представляющие описанные виды фасадных систем. **Результаты.** Определён формообразующий потенциал стеклянных конструкций; проанализированы роль и место светопрозрачных витражных ограждающих конструкций в формировании архитектуры зданий, обеспечении взаимосвязи внешней и внутренней среды; разработана новая классификация современных типов витражных фасадов по архитектурно-конструктивному признаку.

Ключевые слова

Светопрозрачные витражные ограждающие конструкции, свет, стекло, фасад, система остекления фасада, классификация.

Civil Engineering

OVERVIEW OF GLOBAL DESIGN EXPERIENCE AND A DESIGN OF A MOBILE CONSTRUCTION 3D PRINTER

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Abstract
Introduction: The paper presents a brief overview of current construction 3D printing possibilities and a detailed analysis of a design of a mobile construction 3D printer. The authors analyze advantages, disadvantages and development prospects of the construction method. Based on the analyzed data, they describe the development of a conceptual design for such a printer characterized by the structure built-up of basic modules with a length of 1 m, the possibility of printing in the field without preliminary site preparation, the use of construction wastes as a concrete mix aggregate. The authors highlight that the design can be used both in the system of logistical support of the Russian Federation Armed Forces and for civil purposes to construct various facilities. They conclude that it is reasonable to perform further studies in this area and describe prospects of project development. **Methods:** In the course of the study, the authors compared and analyzed specifications of construction 3D printers to refine the specifications of the design developed. **Results:** Based on the analysis and comparison of structures and application fields of analogs, a conceptual design of a mobile construction 3D printer for the Russian Federation Armed Forces was proposed. **Discussion:** A prototype in scale 1:5 was presented at the International Military-Technical Forum “ARMY-2019” (Popov, 2019).

Keywords
Construction 3D printing, logistical support of the Russian Federation Armed Forces, gantry 3D printer, construction site.

Introduction

The construction industry is leading in the number of jobs around the world. It ensures economic development and improves living standards. It is also one of the major industries in Russia accounting for 8% of the GDP (Electronic Scientific Journal “Apriori”, 2018). As in the rest of the world, the construction industry is the least automated in comparison with mechanical engineering and other industries. It is evident that to automate construction it is necessary to replace manual labor with innovative technologies for the manufacturing of building structures. Construction 3D printing is an example of such technology improving manufacturing automation manifold. With 3D printing, speed and technological efficiency of structural construction significantly increase, and labor intensity and expenses significantly decrease. The use of a mobile construction 3D printer at a construction site is a step towards modernization, cost-cutting regarding the cast-in-place construction method.

Scope and tasks of the study

Subject of the study: Construction 3D printing technology.

Scope of the study: Mobile construction 3D printer for the printing of temporary and permanent structures in-situ.

Tasks of the study:

1. Reviewing global experience in project design, engineering and industrial use of construction 3D printers.
2. Identifying advantages and disadvantages of the technology, studying various types of printers.
3. Determining the rationale for the use of the studied technologies both in the system of logistical support of the Russian Federation Armed Forces and for civil purposes.
4. Developing a conceptual design, creating a preliminary 3D model.
5. Performing test runs of the project at technical forums, innovative displays.

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6. Obtaining a utility model patent.
7. Preparing detailed design documentation to create a prototype.

Results of the studies

Literature review

Construction mixes and their use in 3D printing were considered in detail by Torshin and Potapova (2016). The following conclusion was made: introduction of water-retaining, thickening and other additives into a concrete mix makes it possible to use construction mixes in 3D printing.

Analysis of printed samples tested under different types of loading confirmed the proposed theoretical framework regarding the behavior of a concrete mix (Perrot et al., 2016).

To print a building, a 3D mathematical model is required. Such a model can be developed in 3D modeling or 3D BIM software. Using Autodesk Revit, Edenhofer et al. (2016) studied the development of a structural model for printing.

Additive technologies are successfully used in many areas, such as mechanical engineering, shipbuilding, astronautics, medicine and pharmacology, agricultural industry. Global experience in construction includes examples of implementing projects using a construction 3D printer, and features numerous versions of printer structures.

Reviewing global experience in project design, engineering and industrial use of construction 3D printers

To get a general idea of construction 3D printing development, an infographic developed by Langenberg (2015) can be used. It covers manufacturing projects, i.e. with a manufactured prototype (Figure 1). The infographic represents a map where projects are classified by location, time and material.

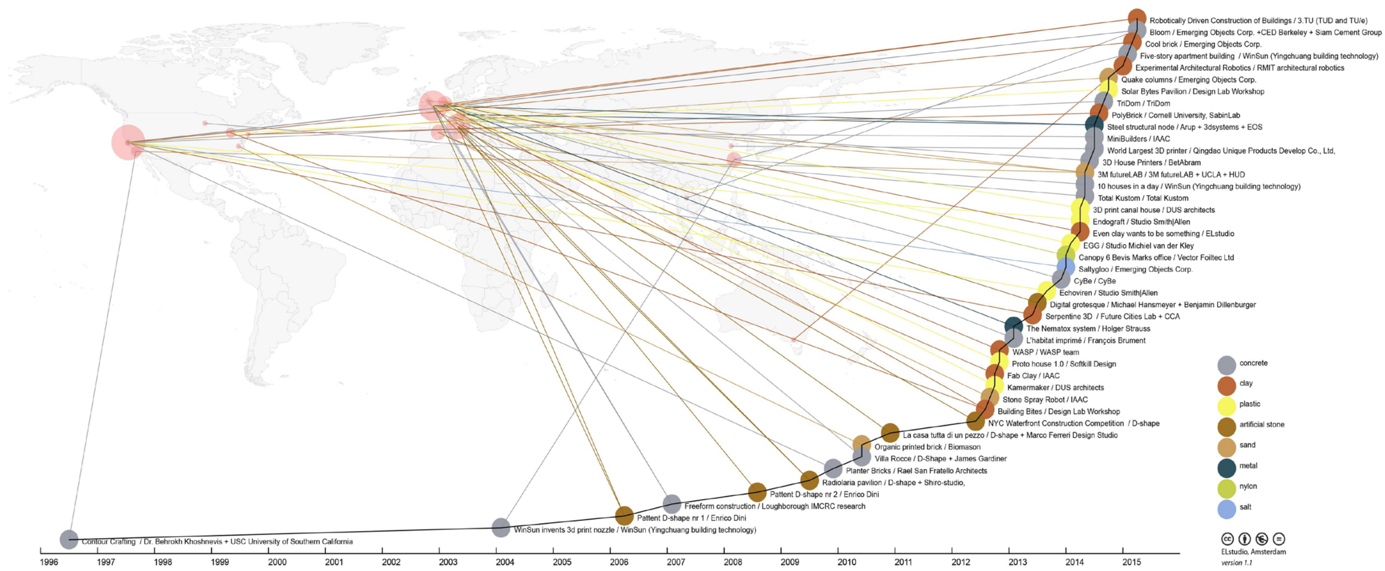

Figure 1. Diagram for the appearance of construction 3D printing projects (from 1995 to 2015).

As can be seen, 2012 was a turning point. The number of designed 3D objects increased manifold, _and the linear progression turned into an exponential one._

According to the diagram, the most major representatives of the industry are:

1. WinSun (China);
2. SpecAvia (Russia).

Chinese company WinSun remains a global leader in the application of construction 3D printing technologies and the number of constructed residential buildings (Demidenko et al., 2017). Its construction printers are stationary. They are located in large workshops and print parts of buildings and their deliverable assemblies. Then buildings are assembled from large modular units at construction sites (Figure 2).

Figure 2. Assembled building at a construction site.

On the practical level, WinSun implemented the largest number of construction projects using the 3D technology. The company plans to develop further and build more than 100 3D printing plants (Litvintseva, 2016).

As one of its projects, WinSun constructed a five-story residential building with an area of 1100 sq. m. The building was assembled at a construction site from large deliverable assemblies printed at a plant. After the assembly, heat insulation and HVAC systems were provided, window and door openings were made.

At the end of the construction, the following conclusions were made:

1. As compared with the traditional method (regarding the construction of an equivalent building), savings in construction materials amounted to 60%.
2. The building was constructed three times faster.
3. The amount of construction wastes decreased by 30–60%.
4. The labor costs decreased by 50–80%.

The last two conclusions result in the improvement of the environmental friendliness of construction products and a significant reduction in the rate of occupational injuries at a construction site.

In Russia, scientists and engineers carry out researches in the field and develop prototypes of construction 3D printers as well. SpecAvia company (www.specavia.pro) reached the level of practical use and commercial sales for its products, and now it offers several types of such printers (Figure 3).

Figure 3. AMT S-6044 LONG2 construction 3D printer.

Currently, approximately 35 companies are engaged in the development of construction 3D printer prototypes. These 3D printers can be classified by the type of structure:

- Gantry printers (WinSun, SpecAvia).
- Circular printers (Apis Cor).
- Robot printers (Batiprint3D, ProTo R 3DP).

Identifying advantages and disadvantages of the technology

Advantages (in addition to those indicated above)

Minimum labor costs: Human operators are needed only for equipment monitoring, maintenance and installation.

Minimum construction wastes: The construction process results in the production of dozens of tons of solid wastes. Using a waste grinder, it is possible to re-use construction wastes as a part of a concrete mix.

Architectural freedom: The technology gives architects, designers, and builders an opportunity to create any complex curvilinear surface in the automatic mode.

Disadvantages

Currently, the main disadvantage is the fact that only vertical structures (walls) can be printed.

Codes and standards: To ensure large-scale implementation of this construction method, corresponding codes and standards are required to be embedded in the construction industry of the Russian Federation. This is possible only after thorough research.

No coordination of developments: There is no unified scientific database in the world that would combine the results of developments. All companies and initiative groups conduct independent developments. Moreover, each of them starts works almost from scratch.

Due to specifics of printer operation, it is impossible to print a smooth wall surface. Plastering and cladding are required.

Structures of walls erected using a construction 3D printer

Irrespective of the construction method, any wall shall meet all strength and heat insulation requirements. In plan view, a wall represents a lattice framework with cavities. These cavities are filled either with a concrete mix with principal vertical reinforcement or heat insulation material. Such wall cavities are also used to lay required utility lines.

Determining the rationale for the use of the studied technologies both in the system of logistical support of the Russian Federation Armed Forces and for civil purposes

Considering the above, we can conclude that the method shall be embedded in the system of logistical support of the Russian Federation Armed Forces. They need a mobile construction 3D printer that would print field camp and military town infrastructure. Such a building construction method can also be useful in emergency response and recovery.

The design of a mobile construction 3D printer has dual purpose:

To be used in the system of logistical support of the Russian Federation Armed Forces:

Construction 3D printing of barracks using local materials, energy-efficient buildings in places of temporary settlement, retained formworks for fortification structures in-situ, and for the repair of existing structures.

The use of 3D printers makes it possible to improve the automation of settlement for the Armed Forces of

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the Russian Federation Ministry of Defense, increase the efficiency of units in the field, reduce time for the setup of a temporary settlement.

To be used for civil purposes at a construction site:

Printing of individual building structures (in particular, complex non-standard elements), small buildings and architectural forms. Recycling of construction wastes by their grinding and adding to a concrete mix as an aggregate.

Due to the use of 3D printers, it is possible to significantly reduce the volume of manual labor, time required for erection, and cost of works. It is also possible to reduce time for the preparation of detailed drawings as printers use 3D models of structures, taken from BIM models, directly.

3D printers can also be used for printing of structures in temporary transfer areas, fast construction in places of natural disasters.

Developing a conceptual design, creating a preliminary 3D model

Analysis of an AMT S-300 construction 3D printer analog

AMT S-300 (SPECAVIA, 2019) is a large-format gantry construction printer with a production capacity of 2.5 cubic meters per hour (Figure 4).

Figure 4. AMT S-300 construction 3D printer.

The printer has a frame with four columns attached to the foundation at a construction site. Electric hoists (stepper motors with planetary gearboxes) mounted on the columns gradually lift a frame consisting of two beams with another mobile beam mounted on them, which has a boom with a direct-flow print head for fast printing. To ensure fast printing, a station that prepares and feeds concrete to the print head is provided. The set also includes a high-pressure washer for equipment cleaning. The printer is equipped with a laptop (with licensed software installed), control cabinet, electric hoists, station for automated preparation and feeding of a concrete mix. The construction printer uses commercial and structural concrete based on 400/500 cement with a fraction up to 6 mm, as well as geopolymer concrete.

This construction 3D printer has a simple frame, a large printing area up to 120 m^2 (maximum dimensions: 11.5x11.0x5.4 m), and a service life of 60,000 hours.

The design aims to resolve the following task: to develop such structure of a printer that would allow for transportation, installation in-situ without special machinery, and printing of buildings and structures directly on an uneven surface.

Using the design, it is possible to obtain the following technical results: simplified transportation and quick assembly of a construction 3D printer without special machinery, its installation at a site with difference in elevation.

These results can be achieved by dividing the frame into uniform modules with a length of 1 m, to which gear and mechanisms are attached, and by using adjustable bases with the maximum difference in elevation of 30 cm.

The uniform module structure has a number of advantages: durability, stability, and low weight. Therefore, it is possible to assemble a printer manually.

Based on the performed analysis, the designed 3D printer (Figure 5) adopts a gantry structure due to its simplicity (which is especially important in the field) and relatively low price.

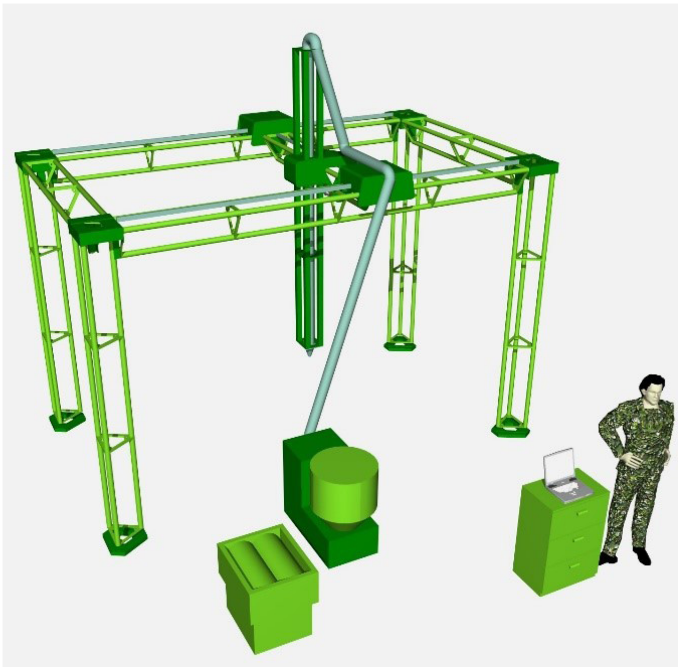

Figure 5. Mobile construction 3D printer for the printing of temporary and permanent structures in-situ.

The construction 3D printer has adjustable bases, which bring the printer to the active position and align it horizontally and vertically. Basic modules are the main elements of the frame composing rail beams, joining beams, a mobile beam, and columns. The rail beams are installed along the long side of the frame and intended for the movement of the mobile beam with an extruder column mechanism. The joining beams are installed along the short side of the frame and intended to join the frame of the main columns and the beams. By means of an X-axis device, the mobile beam moves along the rail beams together with the extruder column, which, in turn, moves relative to the mobile beam along the Y and Z axes by means of a corresponding device.

The construction mix is supplied through a flexible hose by the automatic device that prepares and feeds it. This device reminds an automatic concrete mixer. It has a pump to feed the mix and ensure the required pressure in the hose. During printer operation, it is possible to use construction wastes and local materials. To grind those and turn them into an aggregate, a shredder is used. The printer is controlled with hardware used by an operator. The hardware includes a control unit for the mix preparation and feeding device, a CNC unit, and an operator workstation.

The printer and its components are shown in Figure 6.

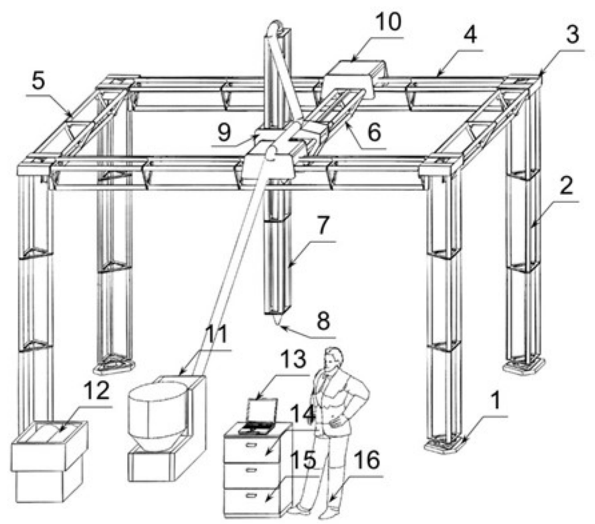

Figure 6. Schematization of the printer and its components.

The device has the following components:

1. adjustable bases
2. basic modules
3. rigid assembly joints
4. rail beams
5. joining beams
6. mobile beam
7. extruder column
8. extruder
9. Y- and Z-axis device
10. X-axis device
11. device for mix preparation and feeding to the print head
12. shredder
13. hardware
14. control unit for the mix preparation and feeding device
15. CNC unit
16. operator workstation.

The power supply is provided by standard mobile diesel generators (220 V) used in field camps of the Russian Federation Armed Forces. Design performance characteristics are provided in Table 1.

Table 1. Performance characteristics

Characteristics	Values
Loaded weight, t (max)	0.35
Type	gantry
Dimensions of a basic module, mm – Length – Width/Height	 1000 300
Operating conditions – temperature, °C	–25…+50
Production capacity, m^3/hour	0.5…2.5
Power consumption, kW*h	3–5
Maximum dimensions of the built-up frame, m – Length – Width – Height	12 6 5

Relevance of the task being solved

Economic relevance: Modernization of the construction industry and application of new technologies are priority tasks of development. Economic advantages related to the 3D printing of structures and low-rise buildings are the following:

- Reduction of material consumption due to a decrease in demand for extra construction materials and tools.
- Reduction of power costs.
- Reduction of costs for the construction of buildings with unique architecture.
- Significant reduction of costs for the recycling of construction wastes.

Environmental relevance: During construction of buildings with traditional methods, a large amount of construction wastes is generated, which is not processed or recycled. Construction by means of a 3D printer is zero-waste. In this case, construction debris can be recycled and re-used if a shredder is used to grind it and add it to a construction mix.

Social relevance: A 3D printer can be very useful in emergency response and recovery, construction of comfortable temporary and permanent buildings for victims of natural disasters.

Technical and economic efficiency of design utilization

Based on the experience in using 3D printers manufactured by WinSun (Demidenko et al., 2017), SpecAvia (www.specavia.pro) and Apis Cor (Mukhametrakhimov and Vakhitov, 2017), the following utilization efficiency can be expected: a decrease in the amount of construction wastes by 30–60%, reduction of construction time by 40–70%, and a decrease in labor costs by 50–70%. The printer is built-up of basic modules with a length of 1 m (Figure 7). This makes it possible to disassemble and move the printer easily, and adjust the dimensions of the area from 3 to 12 m.

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Figure 7. Basic module (with a length of 1 m).

Options for the arrangement of the printing area (8x4, 8x2) are shown in Figure 8.

Figure 8. Options for the arrangement of the printing area.

Conclusions

Construction 3D printing makes it possible to significantly reduce:

Construction costs

Construction time

Labor intensity, volume of manual labor

Construction wastes

The use of 3D printers in the Russian Federation Armed Forces will make it possible to increase the efficiency of units in the field, reduce time for setup and automation of settlement for the Armed Forces of the Russian Federation Ministry of Defense, implement innovative solutions with regard to the construction and repair of military towns and posts.

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АНАЛИЗ МИРОВОГО ОПЫТА КОНСТРУИРОВАНИЯ И РАЗРАБОТКА МОБИЛЬНОГО СТРОИТЕЛЬНОГО 3D-ПРИНТЕРА

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Аннотация

Введение. В статье приводится краткий анализ возможностей строительной 3D – печати на настоящее время и подробно рассмотрена разработка мобильного строительного 3D – принтера. Проанализированы достоинства и недостатки технологии, перспективы развития. На основе проработанной информации показано создание эскизного проекта принтера с отличительными особенностями: сборная конструкция с основным модулем длиной один метр, возможность печати в полевых условиях без предварительной подготовки площадки, использование строительных отходов в качестве заполнителя бетонной смеси. Указано практическое применение проекта как в системе материально – технического обеспечения Вооруженных Сил Российской Федерации, так и в гражданских целях для возведения различных объектов. Сделаны выводы о целесообразности дальнейших исследований в данной области и перспективах развития проекта. **Методы.** Было произведено сравнение и анализ технических характеристик строительных 3D – принтеров для уточнения характеристик разрабатываемого проекта. **Результаты.** На основе анализа, сравнения конструкций и области применения аналогов был предложен эскизный проект мобильного строительного 3D – принтера для ВС РФ. **Обсуждение.** Разработка в виде макета в масштабе 1:5 была представлена на Международном военно-техническом форуме «АРМИЯ-2019» (Попов, 2019).

Ключевые слова

Строительная 3D – печать, материально – техническое обеспечение ВС РФ, портальный 3D – принтер, строительная площадка.

CONCERNING THE RATIO BETWEEN THE ADHESIVE AND MECHANICAL STRENGTH OF BUILDING STRUCTURES – 3D PRINTING PRODUCTS OBTAINED BY FUSED DEPOSITION MODELING OF THERMOPLASTIC MATERIALS

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Abstract

Introduction: 3D printing represents a very promising area in the construction industry. However, the lack of a theoretical framework, which makes it impossible to control the quality of structures obtained, prevents it from being used in mass production. **Methods:** Adhesion properties largely depending on the cross-section area are one of the most important elements of the technology, which in some cases limit the strength characteristics of a resulting structure. Therefore, it is necessary to know adhesive strength characteristics (besides mechanical ones) of items manufactured using this technology. The paper addresses strength characteristics of a joint between the layers of the extruded material when a structure is manufactured by 3D printing. The authors experimentally determine a dependency of the ratio between the adhesive and mechanical strength on the layer printing time. **Results:** The practical result of the study is in the revealing of a general relationship in 3D printing both in the area under consideration and in the construction field, and the improvement of the theoretical framework for further development of the technology in the construction industry.

Keywords

Polymer materials, additive manufacturing, fused deposition modeling, mechanical strength, adhesive strength, construction 3D printing.

Introduction

Construction 3D printing moved beyond theoretical studies and scientific papers long ago. Currently, layer-by-layer extrusion (or fused deposition modeling) is the most commonly used method in the area under consideration, and concrete is the basic material (Demidenko, Kulibaba, Ivanov, 2017).

As a result of technology improvement, Shanghai WinSun Decoration Design Engineering Co. improved the performance of printed buildings in comparison with that of buildings constructed according to the traditional technology. Printed buildings are 2 times efficient in terms of the construction and installation cost, 2.5 times efficient in terms of material consumption, and 5 times efficient in terms of labor intensity (http://robotrends.ru/pub/1718/top-6-stroitelnych-printerov-dlja-3D-pechati-domov, accessed on: 01.12.2018). These results apply to buildings up to five stories high. This indicates that construction 3D printing is developing and expanding in civil engineering, taking the place of the traditional technology and competing with it in the sphere of low-rise construction.

As a result of layer-by-layer extrusion of a construction mix in 3D printing, we get a structure "covered" with concrete joints. However, a joint obtained as a result of extrusion is not equivalent to a cold joint. According to Paragraph 5.3.12 of the Set of Rules SP 70.13330.2012 Load-Bearing and Separating Constructions, it is possible to proceed with concreting when at least 1.5 MPa strength is gained, which cannot be ensured during 3D printing. Therefore, a joint obtained (hereinafter referred to as "'printing" joint) cannot be considered as a cold joint. According to Paragraph 5.3.9 of the Set of Rules SP 70.13330.2012, the next layer of a construction mix shall be laid prior to the setting of concrete in the previous layer. Therefore, a printing joint cannot be considered as a homogeneous material in design.

Thus, in terms of the regulatory framework covering joint analysis, printing joints represent a topic that has not been addressed yet. The lack of a regulatory framework makes it impossible to use the technology in the Russian Federation for the construction of buildings and structures, design documentation of which shall be reviewed by

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expert examination authorities, i.e. buildings with more than three stories and a total area exceeding 1500 m2 (Urban Development Code of the Russian Federation, Federal Law No. 190-FZ dd. 29.12.2004). This limits the development and application of the technology.

It seems that to perform the analysis of structures manufactured using layer-by-layer extrusion it is necessary to know the relationship between the layer printing time and strength characteristics represented as a ratio between the adhesive strength and the mechanical strength of a 3D printing product.

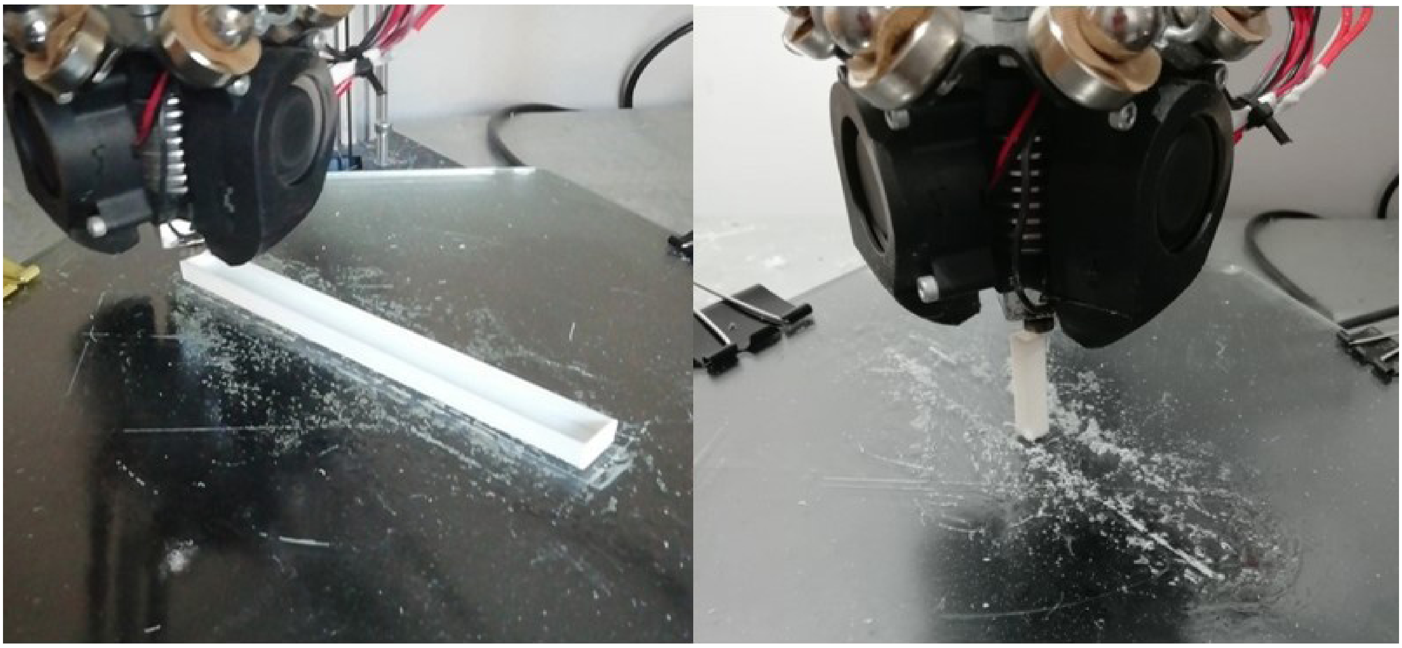
Theoretical studies in this area (in particular, with respect to concrete) are performed with regard to the mechanics of accreted solids. However, such studies address not the strength characteristics of a joint material but the effect of concrete creep on a structure (Rashba, 1953; Kharlab, 1966) and the stress-strain state of a structure during accretion (Kharlab, 2014).

As can be seen, the issue of finding a relationship between the adhesive strength and the mechanical strength in a printing joint is insufficiently studied. Therefore, the purpose of this study is to determine the type of empirical relationship between the parameters mentioned. Results of the study and its further development can significantly expand the scope of construction 3D printing application in the Russian Federation due to the formation of the regulatory framework for the analysis of buildings and structures constructed using a 3D printer.

Methods

Due to the scale factor and specifics of materials applied, it is time-, cost-, and labor-consuming to study the effect of various conditions on the quality of a final product (building structure) and its properties. It seems possible to establish a similarity rule for physical processes in construction and mechanical engineering 3D printing. As for the latter, products and their structural elements have significantly smaller cross-sections. In this paper, items manufactured from polylactide (PLA) by Fused Deposition Modeling (FDM) are considered as a model for 3D printed building products.

Such products are characterized by anisotropy of properties along and across the filaments: under the load along the filaments, the filaments resist; under the load across the filaments, the joints between them resist. In his paper (Petrov et al., 2017) demonstrate that to calculate the mechanical strength of 3D printing products it is required to use samples manufactured horizontally, and to calculate the adhesive strength it is required to use samples manufactured vertically (Figure 1).



a) b)

Figure 1. Arrangement of samples on the table of a 3D printer: horizontal (on the left), vertical (on the right)

The samples are represented by hollow square prismatic bars with a length of 128 mm, wall thickness t_w = 1.2 mm, and sides of 3.2, 4.8, 6.4, and 12.8 mm, respectively (Figure 2). The printing speed is the same for all samples (45 mm/s).

The samples were manufactured using a 3D Quality printer (Prism Mini V2 printer with air cooling of the hot end). The filament was manufactured by Best Filament. It had a diameter of 1.75 mm, white color, and a shelf life of 12 months. The filament was stored under normal conditions within 1 month. The printing temperature was 230°C, and the temperature of the table was 70°C.

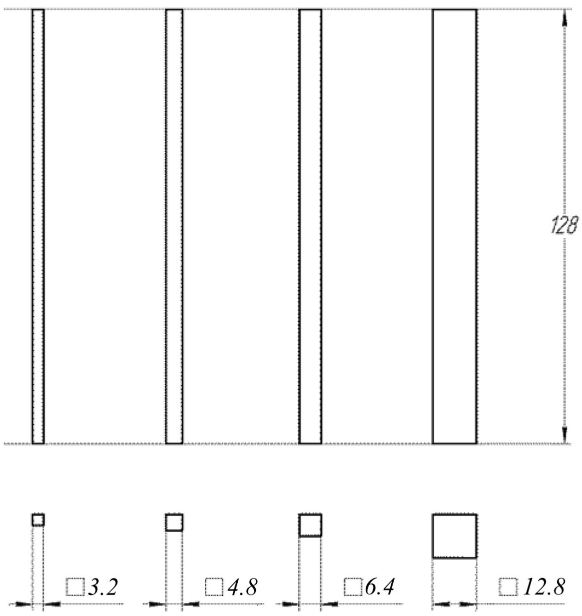


Figure 2. Test samples

The samples were printed horizontally (“h” samples) and vertically (“v” samples). Each batch corresponding to a particular combination of two parameters had five samples.

Each sample was analyzed under axial tension. To test the samples, the authors used an INSTRON 5966 universal electromechanical testing machine.

Based on the analysis of the structure of the “h” and “v” samples, it possible to construct a model linking the load-bearing capacity of the samples F_h and F_v with the mechanical strength σ_m and adhesive strength σ_a of the material, respectively. The model can be represented by equations (1) and (2):

$$\sigma_m = \frac{F_h}{P \cdot t_w} \quad (1)$$

$$\sigma_a = \frac{F_v}{P \cdot t_w} \quad (2)$$

where *P* is the perimeter of the cross-section across the centerline of the wall.

The printing time of one layer was taken as a parameter affecting the strength characteristics. The printing time can be determined by equation (3):

$$t_l = \upsilon \cdot 3 \cdot 2 \cdot (a - 2.4mm + b) \quad (3)$$

where v is the printing speed; a, b are the dimensions of the sample cross-section parallel to the table;

$2 \cdot (a - 2.4mm + b)$ is the centerline of the cross-section parallel to the table; 3 is the wall line count.

Results

Statistical processing of the test results was performed in accordance with an algorithm described in Paragraph 4 and Appendix 3 of State Standard GOST 14359-69 (Plastics. General requirements of the methods of mechanical testing (as amended on 10.04.2018)).

A hypothesis of normal distribution was accepted at the confidence level α = 0.99. As there are five tests in each series, it does not seem possible to compare the obtained distributions with the normal one. Processed results are given in Tables 1 and 2.

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Table 1. Test results in case of the horizontal arrangement of the samples on the 3D printer table

Test No.	Layer printing time $t_{l, i, s}$	No.	F_h, N	Cross-section area, mm^2	σ_{mj}, N/mm^2
1	16.11	3.2h-1	418.39	10.56	39.62
		3.2h-2	429.49	10.70	40.12
		3.2h-3	424.37	10.68	39.74
		3.2h-4	426.53	10.46	40.76
		3.2h-5	435.95	10.49	41.57
				Strength:	40.36 ± 2.11
2	16.32	4.8h-1	723.5	17.74	40.79
		4.8h-2	732.77	17.40	42.11
		4.8h-3	735.66	17.69	41.59
		4.8h-4	751.03	17.59	42.69
		4.8h-5	691.36	17.57	39.35
				Strength:	41.31 ± .39
3	16.53	6.4h-1	1025.41	25.13	40.81
		6.4h-2	1036.29	25.22	41.08
		6.4h-3	1046.44	25.25	41.45
		6.4h-4	1034.4	25.08	41.24
		6.4h-5	971.88	24.84	39.13
				Strength:	40.74 ± 2.44
4	17.39	12.8h-1	2034.78	56.18	12.8h-136.22
		12.8h-2	2160.62	56.62	38.16
		12.8h-3	2048.24	56.14	36.49
		12.8h-4	2009.83	56.16	35.79
		12.8h-5	2014.65	56.18	35.86
				Strength:	36.50 ± 2.53

Table 2. Test results in case of the vertical arrangement of the samples on the 3D printer table

Test No	Layer printing time $t_{l, i, s}$	No.	F_v, N	Cross-section area, mm^2	σ_{aj}, N/mm^2
1	0.53	3.2v-1	376.67	10.49	35.91
		3.2v-2	370.00	10.51	35.20
		3.2v-3	376.93	10.22	36.87
		3.2v-4	371.85	10.30	36.12
		3.2v-5	383.43	10.32	37.15
				Mean:	36.25 ± 2.04
2	0.96	4.8v-1	540.78	16.94	31.92
		4.8v-2	504.12	16.91	29.82
		4.8v-3	510.45	17.02	30.00
		4.8v-4	529.16	17.14	30.88
		4.8v-5	511.03	17.02	30.03
				Mean:	30.53 ± 2.29

3	1.39	6.4v-1	661.75	24.74	26.74
		6.4v-2	602.92	24.58	24.53
		6.4v-3	585.59	24.55	23.85
		6.4v-4	620.96	24.48	25.37
		6.4v-5	576.00	24.69	23.33
				Mean:	24.76 ± 3.51
4	3.09	12.8v-1	1175.76	55.20	21.30
		12.8v-2	1046.19	55.22	18.94
		12.8v-3	1170.43	55.34	21.15
		12.8v-4	1000.17	55.32	18.08
		12.8v-5	1141.35	55.18	20.69
				Mean:	20.03 ± 3.76

The coefficient of correlation between the layer printing time $t_{l,\,i}$ and mechanical strength $\sigma_{mj,\,mean}$ is $r_{x,\,y}$ = -0.913. At $|r_{x,y}|$ from 0.9 to 0.99 on the Chaddock scale, the qualitative assessment demonstrates that the strength of the relationship between these two parameters is very high (https://math.semect.ru/corel/cheddor.php, accessed on: 01.12.2018). It is assumed that the relationship is linear. The coefficient of correlation between the layer printing time $t_{l,\,i}$ and adhesion strength $\sigma_{aj,\,mean}$ is $r_{x,\,y}$ = -0.915, i.e. the qualitative assessment demonstrates that the strength of the relationship between these two parameters is very high. It is assumed that for the “v” samples the relationship is power-law.

To determine equations of the relationship, the least square method is used. Dependency diagrams for the parameters and equations of the approximating relationships are shown in Figure 3.

The obtained mathematical models were checked for informativeness using the Fisher criterion. The calculated value of the Fisher criterion is determined by equation (4):

$$F_{calc} = \frac{S_{res}^2}{S_{av}^2 \cdot (N-p)} \tag{4}$$

where p is the number of assessed model regression coefficients (p = 1 both for the linear and power-law models); N = 4 is the number of test series.

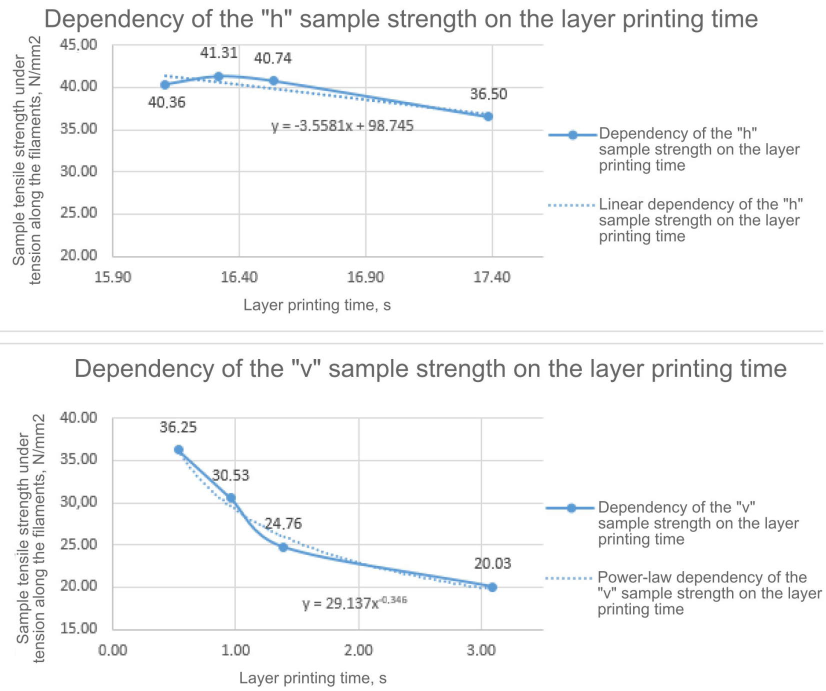

Figure 3. Dependency of σ_m on t (above – for the "h" samples, below – for the "v" samples)

Average response variance is calculated by equation (5):

$$S_{av}^2 = \sum_{i=1}^{N=5} \frac{(y_i - Y)^2}{N-1} \quad (5)$$

Residual variance is calculated by equation (6):

$$S_{res}^2 = \sum_{i=1}^{5} \frac{(y_i - y_\iota)^2}{N-p}, \quad (6)$$

where $\hat{y}_\iota$ is the output value calculated by the regression equation for the i[th] basic test.

The calculated values of the Fisher criterion for the tests of the "h" and "v" samples are equal to 0.055 and 0.006, respectively. The critical value of the Fisher criterion (https://Studfiles.net/prtviev/1740888/, accessed on: 01.12.2018) F_{cr} = 26.83. As $F_{cr} > F_{calc}$ for both mathematical models, then both obtained empirical equations can be considered having informational value.

Dependency k of the actual ratio between the adhesive and mechanical strength on tl is shown in Figure 4. With the use of the least square method, an approximating power-law dependency was obtained. It can be represented by equation (7):

$$k(t) = 0.1907 \cdot t_l^{-1.236} + 0.5 \quad (7)$$

where t_l is given in seconds.

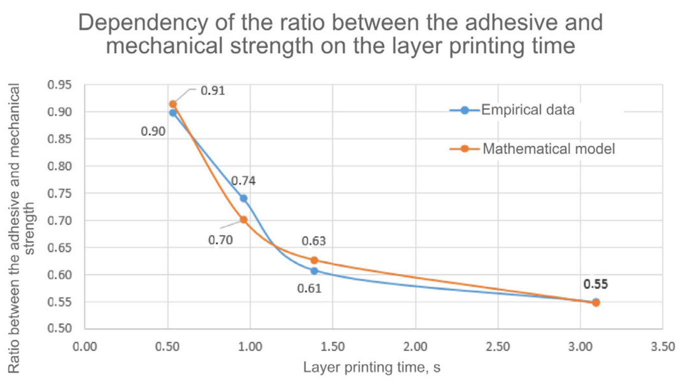

Figure 4. Dependency of the ratio between the adhesive and mechanical strength on the layer printing time

Discussion

The results of the studies confirmed the assumption on the significant effect of time during fused deposition modeling of thermoplastic materials on the adhesive strength of a product (anisotropic material).

The obtained dependency regarding the ratio between the adhesive strength of printing joints and the mechanical strength of the material makes it possible to conclude the following:

1) With an increase in the relative layer printing time, the value of the ratio between the adhesive and mechanical strength decreases according to a law that can be approximated by a power-law function with a sufficient probability.

2) In case of the short relative layer printing time, the strength of adhesive bonding approximates the strength of cohesive bonding (mechanical strength), and with an increase in the layer printing time, it approximates the strength of one-sided connections between hardening and hardened filaments.

Based on the results obtained, it is possible to give practical recommendations and determine paths of further studies:

1. the process of printing several products arranged on the table simultaneously decreases their adhesion strength significantly;

2. during 3D printing, it is required to adjust the printing speed based on the cross-section of the item; the algorithm of control program generation shall provide the possibility of setting the variable printing speed;

3. it is required to perform additional studies to analyze the effect of such process factor as the ratio between the layer printing time and solidification time on the resistance to the shearing of the filaments and solve the following tasks:

– to study the effect of the mentioned process factor on components of the strength tensor in the obtained anisotropic material;
– to develop a method to calculate the printing time and trajectory of the hot end relative to the reference surfaces of the item obtained based on the requirements for its minimum weight, fulfillment of strength conditions in each point, and in accordance with the requirements for printing productivity and technological efficiency of products.

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К ВОПРОСУ СООТНОШЕНИЯ АДГЕЗИОННОЙ И МЕХАНИЧЕСКОЙ ПРОЧНОСТИ СТРОИТЕЛЬНЫХ КОНСТРУКЦИЙ – ИЗДЕЛИЙ 3D-ПЕЧАТИ, ПОЛУЧАЕМЫХ ПОСЛОЙНЫМ НАПЛАВЛЕНИЕМ ТЕРМОПЛАСТОВ

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Аннотация

Введение. В строительной отрасли применение 3D-печати является весьма перспективным направлением, но одним из препятствий к внедрению её в массовое производство является недостаточность теоретической базы, вследствие чего управление качеством получаемых конструкций становится невозможным. **Методика испытаний.** Адгезионные свойства, во многом зависящие от площади сечения - важнейшая составляющая этой технологии, подчас лимитирующая прочностные свойства результирующей конструкции. Вследствие чего необходимо достаточно точно знать помимо механических ещё и адгезионные прочностные свойства изделия при данной технологии. В работе рассматриваются прочностные свойства шва между слоями экструзируемого материала при выполнении конструкции по технологии 3D-печати, а также экспериментально определяется зависимость отношения адгезионной к механической прочности от времени печати одного слоя. **Результаты испытаний.** Практический результат настоящего исследования состоит в выявлении общей зависимости для технологии 3D-печати как в исследуемой, так и в строительной сферах, а также в совершенствовании теоретической базы для развития данной технологии в строительной сфере.

Ключевые слова

Полимерные материалы, аддитивные технологии, послойное наплавление, механическая прочность, адгезионная прочность, строительная 3D-печать.

RESOURCE-EFFICIENT METHOD OF WALL ERECTION IN INDIVIDUAL HOUSING CONSTRUCTION USING POLYMER TUBE CONFINED CONCRETE

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Abstract

Introduction: The paper analyzes an experimental load-bearing structure of hybrid cast-in-place and precast low-rise residential buildings using wall panels with polymer tube confined concrete elements. Due to the improvement of design and process solutions, it is possible to decrease the cost, reduce the material and resource intensity of individual housing construction, ensuring structural safety and long life of such buildings. **Methods:** The authors propose a method of manufacturing wall panels, involving industrial production of retained formworks made of polymer tubes and oriented strand board, as well as their subsequent assembly and concreting at a construction site. **Results and discussion:** Results of the study were provided to the New Technologies and Materials in Construction interdepartmental team of the Belgorod Region Department of Construction and Transport. The proposed method is recommended for testing at sites of individual housing construction in the Belgorod agglomeration, including construction financed from the budget.

Keywords

Polymer tube confined concrete, tube confined concrete, retained formwork, frame construction, lightweight concrete.

Introduction.

Modern resource-efficient building structures used in construction engineering – mainly in individual housing construction – are intended to meet social needs of the industry, which define key priorities of individual housing construction: cost-efficiency, reliability, and rapid erection. Innovative building products and technologies are a key aspect in improving the efficiency of individual housing construction in terms of the key priorities and sustainable development of the industry. Such products and technologies decrease the negative impact of the following production factors in construction:

– one-size-fits-all technical solutions, which result in a significant excess consumption of construction resources (in comparison with the minimum acceptable consumption);

– large volumes of highly-skilled manual labor when the standard quality of building products is ensured;

– high costs for the prevention and elimination of manufacturing defects in building products;

– high transportation costs for the delivery of building structures to a construction site.

The rational design of elements for individual residential buildings and the development of a corresponding erection technology alleviate these problems most efficiently. Such elements shall feature the following:

– rational material distribution in accordance with internal forces arising in an element under standard loads;

– universal character of building elements' formation and corresponding spatial and planning solutions;

– maximum prefabrication degree with factory production control;

– structural simplicity and flaw tolerance in case of poor installation;

– use of common, available and cheap resources.

As for individual housing construction, load-bearing wall structures are characterized by the largest volume, highest cost, installation labor intensity, and susceptibility to defects. Both vertical and horizontal loads (caused by wind pressure, non-uniform loading on floor slabs, lateral earth pressure on foundation walls, complex configuration of walls in a plan of a building) are typical for wall structures.

Methods, results and discussion.

Earlier, the authors studied the strength and stress–strain performance of polymer tube confined concrete (PTCC) elements carrying vertical and horizontal loads typical for walls, representing PP and PE industrial tubes filled with heavyweight concrete, common in engineering construction. According to the results of experimental studies, under axial compression of short PTCC columns (with an OD of 110 mm and a height of 400 mm) filled with B15 concrete (with manual compaction),

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a significant increase in cylinder strength (up to 35% in comparison with cube strength for the same quality of concrete) as well as a higher integrity and improved monolithic structure of the concrete core are observed (Shevchenko, Naumov, Dolzhenko, 2015a, 2015b). The horizontal displacements of the PTCC column structure being a part of an above-ground wall were 13% less than the horizontal displacements of the equivalent structure without a casing. When a foundation structure subject to lateral passive earth pressure was modeled, the horizontal displacements of the PTCC column decreased by 7%. Based on these results, we can put the reserve of the load-bearing capacity of PTCC columns in comparison with columns without a casing at 15% max in terms of hardness and 30% max in terms of strength. The reserve of the load-bearing capacity of PTCC walls, averaged for an actual building, shall be estimated closer to the upper threshold as the volume of above-ground walls even in a one-story building exceeds the volume of foundation.

Thus, the use of PTCC in wall structures for individual housing construction is a rational and innovative method of construction that meets the specified criteria of efficiency regarding individual housing construction and matches the behavior of wall elements to a large extent. The use of PTCC represents an efficient technical solution in wall construction, and the use of PTCC columns as a part of a wall is most efficient in combination with a wall filling with cast-in-place heat-insulation concrete and factory-finishing elements acting as a pre-fabricated formwork. The paper addresses methodological and process approaches to the development of an innovative technology for wall construction (in individual housing construction) based on the use of cast-in-place and precast framing constructed at a construction site in a pre-fabricated panel formwork made of large elements with constructed elements of the engineering infrastructure of a building.

The authors studied the resistance of short PTCC columns (with an OD of 110 mm and a height of 400 mm) filled with B15 concrete (with manual compaction) under axial compression. The results of an analysis of samples obtained by sawing a short PTCC column into thin slices showed a high density of the concrete core.

According to the results of an axial load test, concrete cylinders are destructed in a standard way (their sides are crushed and longitudinal cracks appear), and the strength of PTCC columns in a PE casing is higher than that in cubes by 35% max, and higher than that in a PP casing by 15% max (Table 1).

To study the type and nature of the physical nonlinearity of the deformation in a polymer casing, the authors determined experimentally the deformation characteristics of PE in PTCC tubes using a WEW-600D universal hydraulic testing machine. The longitudinal and transverse strains were measured automatically with a 0.01% load step. Results of the tests are shown in Figure 1. The polymer casing in PTCC columns demonstrates a significant physical nonlinearity of stress–strain properties (Figure 2). The stress–strain modulus E decreases from 1200 to 280 MPa with an increase in strain rate (ε) up to 5.3%.

Table 1. Axial load test of short PTCC columns

No.	Ultimate load, t	Average bearing capacity, t
1	12.25	
2	9.75	10.9
3	10.75	
4	16.5	
5	11.25	14.7
6	16.25	
7	12.75	
8	12.5	12.5
9	12.25	

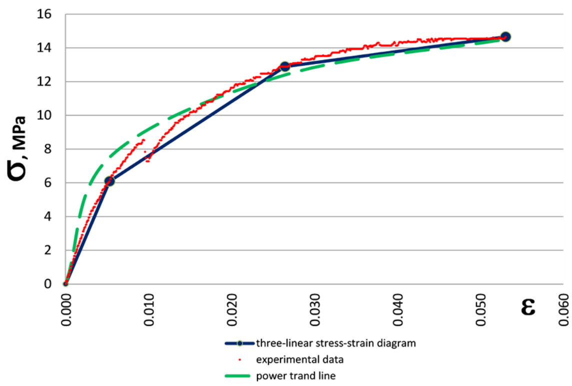

Figure 1. Stress–strain curve for a polymer casing (experimental data obtained by the authors).

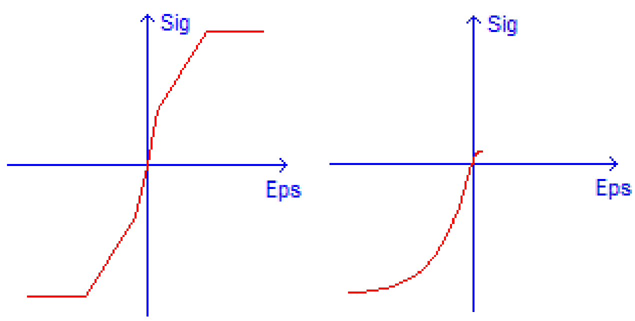

Figure 2. Exponential stress–strain curve for concrete (on the left) and three-line stress–strain curve for a polymer casing (on the right) used in FEM numerical simulation.

A universal wall panel made of oriented strand board (OSB) sheets combined through special intermediate elements with hollow plastic tubes installed inside the sheet at particular intervals and height represents a structural element of the proposed method (Figure 3).

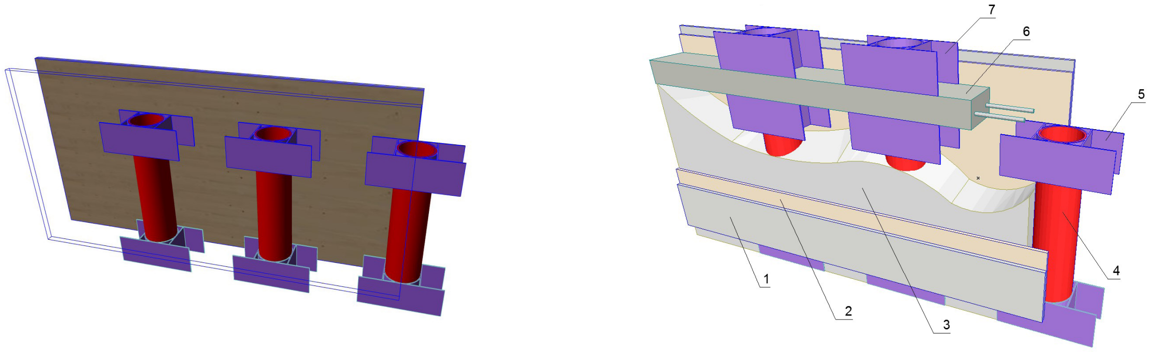

Figure 3. General view of a universal wall panel: on the left – a wall panel with plastic tubes (to be filled with concrete); on the right – a wall panel filled with concrete: 1 – interior finishing; 2 – an internal layer of OSB; 3 – heat insulation with precast foam concrete; 4 – a PTCC column; 5 – an intermediate element; 6 – a horizontal reinforcement frame in each tier of panels (made of precast heavyweight concrete); 7 – an intermediate element of the overlying tier of panels.

The process of wall construction as per the proposed method includes the following steps:

1) the panels are installed in tiers along the perimeter of inner and outer load-bearing walls; the panel sheets are joined with decorative vertical coupling elements (Figure 2);

2) the tubes are filled with heavyweight concrete of specified class; the PTCC columns are reinforced (if necessary) in accordance with the specified stress–strain state for each panel individually;

3) the space between the PTCC columns is filled with lightweight precast heat-insulation material (e.g. precast foam concrete or polystyrene concrete) below the bottom elevation of the horizontal reinforcement frame binding the panels along the perimeter (Figure 1);

4) a reinforcement cage is installed, heavyweight concrete to grout the horizontal reinforcement frame is filled below the bottom elevation of the intermediate elements of the overlying tier of panels;

5) wall panels of the next tier are installed in a staggered order (being shifted at a distance between two or three columns); the panel sheets of the adjacent tiers are joined with decorative horizontal coupling elements.

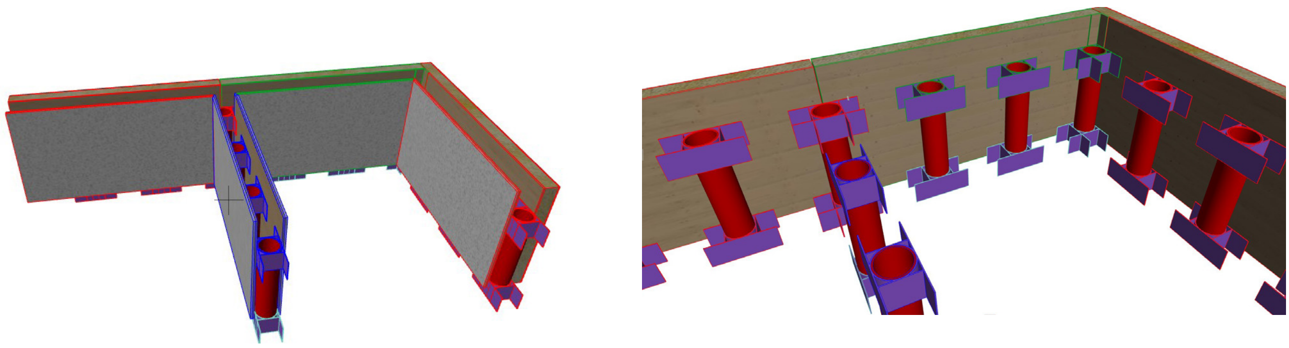

Figure 4. Wall panels installed in a tier (to be filled with concrete): on the left – sheets of internal and external prefabricated finishing; on the right – tubes of internal PTCC columns with installed intermediate elements.

Innovative intermediate elements made of plastic similar to that used in PTCC tubes and manufactured based on the extrusion technology are of particular interest. These universal elements can be adapted by cutting off unnecessary fragments (with subsequent recycling), which makes it possible to join panels in a tier horizontally in a wide range of joint combinations (Figure 3). Therefore, it is possible to use standard joint units and, using panels proposed, assemble internal and external wall structures of arbitrary rectangular configuration (Figure 4) that meets the requirements of various spatial and planning solutions in individual housing construction, preserving their maximum functionality and resource efficiency.

To ensure practical use of panels proposed and corresponding automated document management, the authors suggest a template for the identification of such panels, including basic data required by a manufacturer and provided by a designer / BIM program when automating the process of arranging wall panels in a plan of a building.

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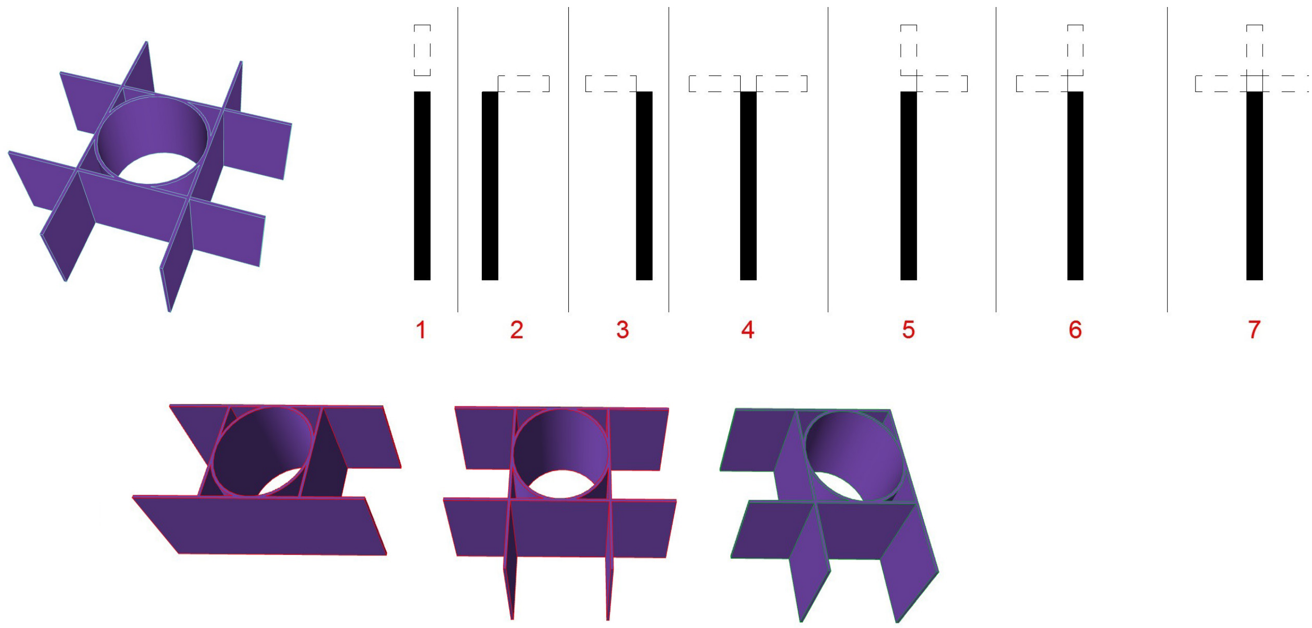

Figure 5. Universal intermediate element (on the left), options of joining wall panels horizontally in a tier using an adaptable intermediate element (on the right), and options of adapting an intermediate element to join panels in a tier as per different options (below).

Figure 6. Floor plan of an individual residential building (on the left) and a layout of proposed wall panels during construction and installation (on the right).

Conclusion.

The proposed method is intended to be improved in terms of the detalization of coupling elements, insulation and finishing layers, method of applying prefabricated internal and external finishing materials, elements of utilities. Software algorithms for automation of building design with the use of proposed wall panels based on BIM technologies are developed. In general, the proposed method represents one of the options to use PTCC structures in resource-efficient individual housing construction, demonstrating that it is efficient and reasonable to use PTCC in construction engineering.

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РЕСУРСОЭФФЕКТИВНАЯ СТЕНОВАЯ ТЕХНОЛОГИЯ ИНДИВИДУАЛЬНОГО ЖИЛИЩНОГО СТРОИТЕЛЬСТВА НА ОСНОВЕ ПЛАСТИКОТРУБОБЕТОНА

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Аннотация

Введение. В статье рассматривается экспериментальная несущая конструкция сборно-монолитных малоэтажных жилых домов с применением стеновых панелей с пластикотрубобетонными элементами. Снижение стоимости, материалоемкости и энергоемкости строительства индивидуальных жилых домов при условии обеспечения их конструктивной безопасности и долговечности может быть достигнуто оптимизацией конструктивных и технологических решений. **Методы.** Авторы предлагают технологию изготовления стеновых панелей, которая включает в себя индустриальное изготовление несъемных опалубок из полимерных труб и ориентированно стружечных плит, с последующей сборкой и бетонированием на месте строительства. **Результаты и обсуждение.** Результаты проведённых исследований были представлены межведомственной рабочей группе «Новые технологии и материалы в строительной отрасли» Департамента строительства и транспорта Белгородской области. Предлагаемая технология рекомендована к апробации на реальных площадках индивидуального жилищного строительства Белгородской агломерации, в том числе финансируемого из бюджетных средств.

Ключевые слова

Пластикотрубобетон, трубобетон, несъемная опалубка, каркасное строительство домов, легкий бетон.

ISSUES RELATED TO THE ADHESION BETWEEN DEFORMED REINFORCEMENT AND CONCRETE

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Abstract

Introduction: Based on an analysis of issues related to the anchorage and active adhesion between deformed reinforcement and concrete, it is possible to identify major problems of concrete-to-steel bond breaking during the operation of bearing building structures. **Purpose of the study:** The authors seek to determine the mechanism of interaction between concrete and steel in the adhesion contact area, establish a relationship between external force action and crack development in the contact area. **Methods:** The authors suggest some dependencies to evaluate various test methods when determining the area where two materials, differing in physical characteristics, interact. Approximation to the actual phenomena related to the interaction between concrete and reinforcement, starting from the moment when through and non-through internal cracks form in the contact area and ending with destruction, is a general problem of models describing the adhesion of materials. **Results:** The theoretical results were compared with the experimental data and recommendations of modern regulatory documents, and it was found that they are in a satisfactory agreement. It was established that the difference of axial deformations of the bar and the surrounding concrete goes into the difference of bending displacements, which explains uneven load distribution across the protrusions. **Discussion:** Using the suggested dependencies, it is possible to predict crack development in the contact area of the reinforcement and cement binder as well as in the slip area in an extreme case. The concrete tensile strength in particular reinforced-concrete elements in supporting cross-sections and with anchorage in tensile concrete represents a factor affecting the strength of the concrete-to-steel bond.

Keywords

Anchorage, reinforcement adhesion, concrete.

INTRODUCTION

According to the results of studying the concrete-to-steel bond, no sufficiently reliable theories have been developed yet, where the relationship between shear stresses and displacements would be based on contact problems. Such problems are solved using additional assumptions, including numerical methods. Some researchers (Karpenko and Gorshenina, 2006; Karpenko and Karpenko, 2001; Prokopovich, 2000; Savrasov, 2009; Sechenkov et al., 2007; Zikeev and Tsyba, 2009) modeled the mechanical interaction of materials in the active concrete-to steel bond area. This area is represented by conical shells. In this case, the effect of moments, normal and transverse forces, as well as circumferential cracks, is taken into account (Karpenko and Karpenko, 2001). The obtained resolving equations are represented in finite differences. Solving a system of equations of the 26th order, it is possible to determine reinforcement displacements relative to concrete. One of the traditional tests performed when studying the adhesion of materials is a pull-out test, i.e. pulling reinforcement bars out of a concrete prism (cylinder) supported at its end face. Besides, reinforcement anchorage in tensile concrete has received almost no attention from researchers.

An analysis of studies related to the concrete-to-steel bond reveals a mixed approach to the solution (Kashevarova et al., 2016), a lack of a uniform and theoretically substantiated method of calculation (including under non-linear conditions): there is no unified approach to the solution of a problem in obtaining an equation for the compatibility of deformations for various types of force application along the length of the contact area of materials; the stress state of concrete and reinforcement in the contact area (both in the presence and in the absence of circumferential non-through cracks) has not been studied sufficiently; there is no clarity regarding the solution of a problem related to the adhesion of materials and their relative displacement at the elastoplastic stage of linear and non-linear concrete creep; materials of the adhesion theory are not sufficiently widely used in practical methods of designing reinforced-concrete structures and analyzing their sections.

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BACKGROUND

Approximation to the actual phenomena related to the interaction between concrete and reinforcement, starting from the moment when through and non-through internal cracks form in the contact area and ending with destruction, is a general problem of the considered models describing the adhesion of materials.

A bond between deformed reinforcement and concrete was taken as a design model (Veselov, 2000) according to the scheme shown in Figure 1. A short sample is pulled out by forces applied to the concrete-free end of the bar embedded in concrete on the one side, and concrete on the other side. The forces are as follows: N3 = N, N4 = 0.

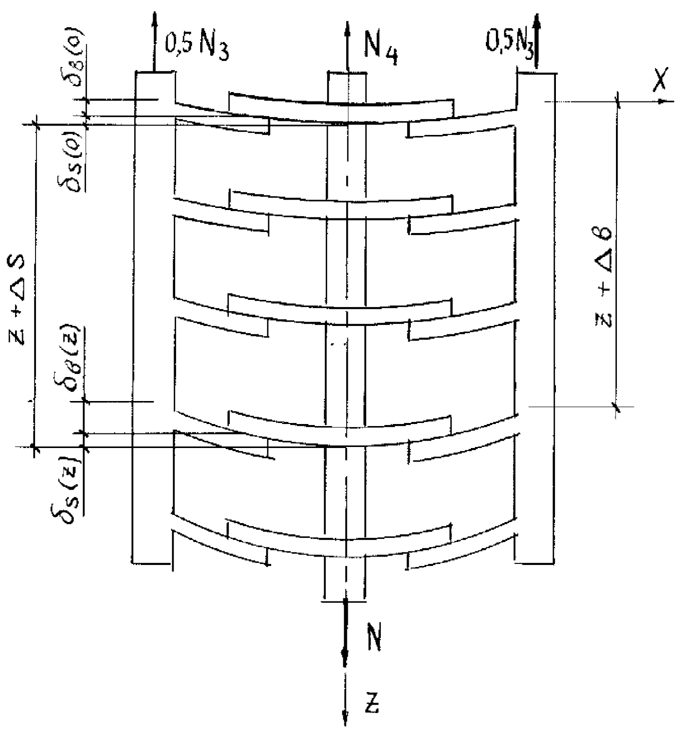

Figure 1.
Concrete-to-steel bond design model

We suppose that inelastic deformations develop in concrete protrusions and that reinforcement protrusions in the contact area are characterized by elastic behavior. Let us accept the following assumptions:

1. In areas of force application from rebars to concrete, the bond is tight.

2. Contacts before and after deformations are observed for all protrusions (Veselov, 2012; Veselov and Chepilko, 2010; Veselov and Pukharenko, 2015).

3. The concrete-to-steel bond is considered as a bond with continuous protrusions.

METHODS

The authors analyze reinforcement anchorage — that is most frequently used in reinforced-concrete structures — pulled out of tensile concrete of a certain area. In this case, tensile forces appear in the contact area as well as the reinforcement. A case when internal circumferential cracks form in the contact area is considered.

CASE HISTORY

Adhesion between reinforcement and concrete can be estimated by the value of shear adhesion acting along the conventional cylindrical surface of the contact area (Veselov, 2000). The convention is in the fact that, even in case of plain reinforcement bars, materials contact along the surface having various protrusions and irregularities. As for plain reinforcement bars, shear adhesion of materials is mainly provided by bonding between the cement gel and reinforcement as well as lateral friction. According to numerous researchers (Choi and Lee, 2002; Choi and Yang, 2010; Karpenko, 2001; Kashevarova et al., 2016, Plevkov et al., 2016), mechanical interlocking due to transverse protrusions on the lateral surface is an essential aspect in adhesion when it comes to deformed reinforcement.

Kashevarova and her colleagues described factors affecting the concrete-to-steel bond strength (Kashevarova et al., 2016). The laws of interaction between concrete and reinforcement determine the specifics of reinforced concrete as a material. The concrete-to-steel bond strength depends on the state of the metal surface, concrete adhesion and cohesion, concrete hardening conditions and age, degree of reinforcement compression during shrinkage, and type of the stress state in the contact area. During loading, the stress state is continuously complicated due to the appearance and development of new transverse and longitudinal cracks breaking the contact between the reinforcement and concrete. Adhesion is conditioned by molecular bonding forces between the surfaces of two dissimilar or liquid contacting bodies. During concrete laying, favorable conditions are created for the manifestation of adhesion in the area of contact with rigid reinforcement.

Concrete plasticity can be increased in the course of vibration compaction. As a result, concrete approaches the metal surface and continuity of contact between them increases. It is known that non-treated steel is wettable and has a tight adhesion with concrete. However, adhesion between concrete and polished steel slightly decreases as continuity of contact at the interface of concrete and treated surfaces is quite high.

RESULTS

In case of the adopted design model of material interaction and taken assumptions, under the action of the force N, the reinforcement bar at some section of length z will elongate by ΔB, and the body of the concrete prism at this section will elongate by Δc . Under external loading, reinforcement bar and concrete protrusions will be subject to bending deformations. Let us denote rebar protrusion deflection in the section z relative to its base by $\delta_b(z)$, and concrete protrusion deflection — by $\delta_c'(z)$.

Based on the taken assumptions and adhesion geometry (Karpenko and Gorshenina, 2006), the condition for the compatibility of deformations can be written as follows:

$$\Delta B - \Delta c = [\delta_b(z) + \delta_c'(z)] - [\delta_b(0) + \delta_c'(0)] \tag{1}$$

where $\delta_b(z) + \delta_c'(z)$ is the sum of reinforcement and concrete protrusions' displacements in the section at a distance z; $\delta_b(0) + \delta_c'(0)$ is the same but in the section z = 0.

It follows from equation (1) that the difference of axial deformations of the bar and the surrounding concrete goes into the difference of bending displacements, which explains uneven load distribution across the protrusions. When deriving dependency (1), the bond model is not significant. Therefore, equation (1) remains valid for other outlines of deformed reinforcement as well (not only for helical).

Let us assume that stresses σ_b and σ_c uniformly distributed across the cross-section act in the bar and surrounding concrete at some distance from the reinforcement surface. Linear displacements in equation (1) can be expressed by force factors:

$$\Delta B = \int_0^z \frac{\sigma_b}{E_b} dz \; ; \; \Delta c = \int_0^z \frac{\sigma_c}{E_c'} dz \tag{2}$$

where E_b and E_c' are reinforcement elasticity modulus and concrete deformation modulus, respectively.

Let us assume that dependency (1) is valid not for any point of the lateral surface regarding protrusions and their outlines, but for points M, Ob, Oc.

Taking the pressure along the protrusions as uniformly distributed and their deformations as isolated from each other, and considering the taken assumptions, linear displacements can be represented by the following equations:

$$\delta_b(z) = \frac{p(z)S_b}{E_{b,v}} \lambda_{b(z)} \; ; \; \delta_b'(z) = \frac{p(z)S_{c1}}{E_{c,v}'} \lambda_{c(z)} \tag{3}$$

where S_c and S_{Cl} — the height of the concrete and rebar protrusions in the contact area; in the absence of circumferential cracks in concrete in the contact area, $S_c = S_{Cl}$, where S_{Cl} — the spacing between the rebar protrusions. $\lambda_{C(z)}$ and $\lambda_{C(z)}$ — dimensionless coefficients that depend on the geometry of the reinforcement, presence or absence of cracks in the contact layer of concrete surrounding the bar, possible defects of concrete protrusions, etc.

Taking into account equations (2) and (3), basic equation (1) can be written as follows:

$$\int_0^z \frac{\sigma_b}{E_b} dz - \int_0^z \frac{\sigma_c}{E_c'} dz = [p(z) - p(0)] \times [\frac{S_b}{E_{b,v}} \lambda_b(z) + \frac{S_{c1}}{E_{c,v}} \lambda_c(z) \tag{4}$$

Let us set boundary conditions at the end faces of the element for the adopted design model:

z = lan	Nb = N;	Nc = 0	
z = 0	Nc = N;	Nb = 0.	(5)

Then, taking into account (5) in the section z, forces in the reinforcement and concrete, respectively, will be as follows:

$$N_b(z) = \int_0^z q_{b1}(z) dz \; ; \; N_c(z) = N - N_b(z) = N - \int_0^z q_{b1}(z) dz \tag{6}$$

Let us establish a relationship between pressure p(z), $q_{b1}(z)$, and $q_{c1}(z)$. Based on the following equations:

$$dN_b(z) = p(z)df = q_{b1}(z)dz$$

and

$$dN_c(z) = p(z)df = q_{c1}(z)dz$$

we obtain $p(z) = q_{b1}(z)\frac{S_{c1}}{f}$ and $p(z) = q_{c1}(z)\frac{S_{c1}}{f}$ (7)

where $f = (\pi d_b - 2b)t_1$ — the projection of the lateral surface of the protrusion on a plane perpendicular to the z axis; d_b — the average diameter of the protrusions, d_b = 0.5 (d+d1) (Karpenko and Gorshenina, 2006) t1 — the effective depth of a protrusion; b — the width of the longitudinal edge.

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Substituting initial data from equation (6) with account for equation (7) in equation (4), we obtain the following:

$$\int_0^z \beta_1(z)[\int_0^z q_{b1}(z)]dz - \int_0^z \frac{N}{E'_c A_c}dz = q_1(z)\gamma_1(z) - q_{b1}(0)\gamma_1(0) \quad (8)$$

At $z = l_{an}$, $q_{b1}(0) = \frac{1}{\gamma_1(0)}[q_{b1}(l_{an})\gamma_1(l_{an}) - \int_0^{l_{an}} \frac{N}{E_b A_b} dz]$ (9)

Transforming equation (9) and taking into account equation (8) we obtain the following:

$$q_{b1}(z) = \frac{1}{\gamma_1(z)}[\int_0^z \beta_1(z)\int_0^z q_{b1}(z)dzdz - \int_0^z \frac{N}{E'_c A_c} dz + q_{b1}(l_{an})\gamma_1(l_{an}) + \frac{N}{E'_b A_b} l_{an}] \quad (10)$$

Equation (10) makes it possible to obtain the intensity of forces distribution along the length of a reinforcement bar, considering the inelastic behavior of concrete in the contact area and beyond. Let us define the line force in the element under consideration with account for the elastic behavior of materials. To this end, we accept the following:

$$\gamma_1(z) = \gamma = \text{const}; \qquad \beta_1(z) = \beta = \text{const}.$$

Having differentiated equation (10) with respect to z and taking $q_{b1}(z) = q_b(z)$, we obtain:

$$\gamma q'(z) - \beta \int_0^z q_b(z)dz + \frac{N}{E_c A_c} = 0 \quad (11)$$

Then we differentiate dependency (11) with respect to z:

$$q''_b(z) - m^2 q_b(z) = 0\,. \quad (12)$$

where $m^2 = \beta/\gamma$, or $m = \sqrt{\beta/\gamma}$ is an adhesion characteristic, which in the general case can be represented as follows:

$$m = \sqrt{\beta/\gamma} = \sqrt{\frac{(1 + \frac{E_b A_b}{E'_c A_c}) f}{E_b A_b \cdot S_{c1} S_b (\frac{\lambda_{b(z)}}{E_{b,v}} + \frac{\lambda_{c(z)}}{E'_{c,v}} \cdot \frac{S_{c1}}{S_b})}}$$

All these values are presented in detail in a paper by Veselov and Chepilko (Veselov and Chepilko, 2010). General integral (12) can be represented as follows:

$$q_b(z) = Ashmz + Bchmz \quad (13)$$

Having differentiated equation (13) with respect to z and taking the boundary conditions at $z = 0$ $q'_b = A_m$:

$z = lan$ $q'_{b(lan)} = Am\,chmz + Bm\,shmz$,

$$A = -\frac{1}{\gamma m} \cdot \frac{N}{E_c A_c}; \qquad B = \frac{N}{\gamma m\, shml_{an}}(\frac{1}{E_b A_b} + \frac{chml_{an}}{E_c A_c})\,.$$

Substituting the values of the A and B constants in general integral (10) and transforming the equation, we obtain the following:

$$q_b(z) = \frac{Nm}{\beta \cdot shm \cdot l_{an}} \cdot \left(\frac{chmz}{E_b A_b} + \frac{chm \cdot (l_{an} - z)}{E_c A_c}\right) \quad (14)$$

CONCLUSIONS

Studying the concrete-to-steel bond, numerous authors came to the conclusion that the compression of reinforcement and concrete protrusions is the main factor in the contact area. According to other researchers, during the interaction of materials, tensile stresses occur that lead to the formation of circumferential cracks (Karpenko, 2001) in the contact area. Based on an analysis of the proposed dependencies, the following can be concluded: regardless of force application, the interaction of materials results in tensile or — when the reinforcement is pulled out of a prism supported at its end face — shear forces in concrete that depend on the concrete tensile strength. The concrete tensile strength in particular reinforced-concrete elements in supporting cross-sections and with anchorage represents a factor affecting the strength of the concrete-to-steel bond.

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ПРОБЛЕМЫ СЦЕПЛЕНИЯ АРМАТУРЫ ПЕРИОДИЧЕСКОГО ПРОФИЛЯ С БЕТОНОМ

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Аннотация

Введение. Анализ состояния вопросов анкеровки и активного сцепления арматуры периодического профиля с бетоном раскрывает основные проблемы разрушения сцепления арматуры с бетоном в процессе эксплуатации несущих строительных конструкций. **Цель.** Раскрытие механизма взаимодествия между бетоном и сталью в зоне адгезионного контакта, установление связей между внешним силовым воздействием и развитием трещин в зоне контакта материалов. **Методы.** Предлагаются зависимости для оценки различных методов испытания при определении зоны взаимодействия двух различных по физическим характеристикам материалов. Общей задачей моделей сцепления материалов является приближение к действительному характеру протекающих явлений взаимодействия бетона и арматуры, начиная с момента образования несковозных и сквозных внутренних трещин в месте контакта материалов вплоть до разрушения. **Результаты.** Проведено сравнение теоретических результатов с опытными данными и предложениями современных нормативных документов, которые удовлетворительно согласуются. Установлено, что разность осевых деформаций стержня и окружающего бетона переходит в разность изгибных перемещений, что и объясняет причину неравномерного распределения нагрузки по выступам. **Обсуждение.** С помощью предложенных зависимостей можно прогнозировать развитие трещин в зоне контакта арматуры и цементного связующего и проскальзывания в предельном случае. Прочность бетона на растяжение в конкретных железобетонных элементах в опорных сечениях и при анкеровке в растянутом бетоне является фактором, влияющим на прочность сцепления в контактной паре «сталь-бетон».

Ключевые слова

Анкеровка, сцепление арматуры, бетон.

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Surface Transportation Engineering Technology

UNIFIED QUANTUM LIFT-AND-TRANSPORT MACHINERY

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Abstract

Introduction: The possibility of energy extraction from the physical vacuum, uncovered in case of potential mastering of the foundations of the theory of Superunification suggested by Leonov, will change the motion mechanics and the pattern of using lift-and-transport machinery if that is equipped with quantum engines (QEs). **Purpose of the study:** The purpose of the study is to develop a conceptual foundation and a working hypothesis for the operation of unified lift-and-transport machinery with quantum thrust – UQLTM. **Methods:** The thrust vector is decomposed into orthogonal components. A generalized force balance equation and its modifications are used. Typical modes of QLTM motion are identified. 3D modeling of force balance with velocity sweeping is carried out. 3D models of force balance are developed using Maple software. Images of surfaces with regard to wind resistance and thrust vector dynamics are built. Calculations as well as graphical-and-analytical studies are performed. **Results:** The paper presents results of calculations with visualization using an example of container transportation from a consolidated terminal to the hold of a container ship with the use of QLTM. **Discussion:** Existing lift-and-transport machines can be replaced by transport machines equipped with QEs (QLTM), and thus it will be possible to make the area of traditional lift-and-transport machinery movement available. Lifting machines can also be replaced by QLTM. Moreover, several types of lift-and-transport machines as well as transport machines used at warehouses to handle cargo can be replaced by unified QLTM (UQLTM) providing continuous transportation of cargo (without any transshipment using different types of vehicles).

Keywords

Quantum engine, quantum thrust, quantum lift-and-transport machinery, force balance.

Introduction

In a number of papers (Kotikov, 2018a, 2018b, 2018c, 2018d, 2019a, 2019b, 2019c, 2019d), the author addressed prospects of using the principles of non-fuel energy production (based on the extraction of energy from the physical vacuum) in the transport industry. The main attention was paid to the issues related to quantum thrust in automobiles with the appearance of a new type of transport – quantomobiles.

Now let us focus on lift-and-transport machinery. The possibility of energy extraction from the physical vacuum, uncovered in case of potential mastering of the foundations of the theory of Superunification (Leonov, 2002, 2010, 2018), will change the motion mechanics and the pattern of using lift-and-transport machinery if that is equipped with quantum engines (QEs).

Unlike ICEs and electric motors, QEs directly generate thrust, which can be applied to the vehicle/machine body (Brandenburg, 2017, Fetta, 2014, Frolov, 2017, Tajmar, 2007. et al.). This creates prerequisites for the appearance of quantum lift-and-transport machinery (QLTM) able to break off the bearing surface and transport cargo hovered over such surface horizontally.

Changing the thrust vector position from horizontal to inclined will make it possible to create a vertical component of thrust, which can be used to overcome gravity and get the QLTM above the bearing surface, allowing it to transport cargo by air (Kotikov, 2018a).

Let us elaborate on this hypothetical thesis.

Purpose and tasks of the study

The purpose of the study is to develop a conceptual foundation and a working hypothesis for the operation of unified lift-and-transport machinery with quantum thrust – UQLTM.

To achieve the purpose, it is required to solve the following tasks:

- to assess specific features and capabilities of QE thrust to ensure lift-and-transport operations related to cargo handling;

- to develop a concept for a new class of unified lift-and-transport machinery – UQLTM;
- to build a mathematical model of QLTM force balance and motion;
- to present basic modes of QLTM operation;
- to analyze a numerical example describing cargo handling with the use of QLTM;
- to summarize the results of the study and offer recommendations for further studies in this area.

Methods

Generalized mathematical model of QLTM force balance

Thrust vector decomposition

The three-dimensional thrust vector can be decomposed into unit vectors (Leonov, 2018, Kotikov, 2019c, 2019d):

$$\mathbf{F_T} = \mathbf{F_{Tx}} + \mathbf{F_{Ty}} + \mathbf{F_{Tz}}. \quad (1)$$

The scalar form of this equation is as follows:

$$F_T = \sqrt{F_{Tx}^2 + F_{Ty}^2 + F_{Tz}^2} \quad (2)$$

If we assume that the thrust vector can be directed in all directions of the 3D space, then the area of thrust vector realization can be represented by a sphere of radius F_T.

If we simplify the task and describe only the longitudinal (course) motion of QLTM in the plane of pitch angle β, then equations (1) and (2) will take the following form:

$$\mathbf{F_T} = \mathbf{F_{Tx}} + \mathbf{F_{Tz}}. \quad (3)$$

The scalar form of this equation is as follows:

$$F_T = \sqrt{F_{Tx}^2 + F_{Tz}^2} \quad (4)$$

Graphically, it is given in Figure 1.

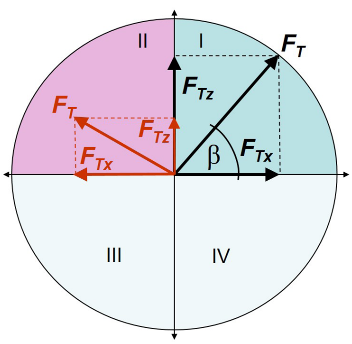

Figure 1. $\mathbf{F_T}$ thrust decomposition into the horizontal ($\mathbf{F_{Tx}}$) and vertical ($\mathbf{F_{Tz}}$) components: β – thrust angle $\mathbf{F_T}$ relative to the horizon.

Equations (3) and (4) are general initial equations for the calculation of QLTM motion both in vertical (with breakoff of cargo from the surface and their lifting) and horizontal direction (transportation of cargo to another location), as well as in case of combined motion along inclined trajectories.

The first (blue) quadrant of the circle formed by the thrust vector tip corresponds to the longitudinal translational forward motion of QLTM (with the realization of direct thrust) (Figure 1). The second (pink) quadrant corresponds to the longitudinal braking modes (reverse).

QLTM and floor-mounted LTM force balance analyses differ. This is due to the fact that the generalized force balance equation involves new entities and physical quantities, which manifest when vertical forces (gravity, hovering, wind resistance to vertical motion, vertical accelerations) are taken into account.

Generalized QLTM force balance equation and its modifications

As a result of equation (4) detalization performed in an analogous way to the way it was performed in other studies (Kotikov, 2019c, 2019d), we obtain the following:

$$F_T^2 = F_{Tx}^2 + F_{Tz}^2 = \left(P_{w.x} + P_{j.x}\right)^2 + \left(P_{w.z} + P_{j.z} + P_g\right)^2 =$$
$$\left(k_{w.x} \cdot S_{front} \cdot V_x^2 + \frac{G_{QLTM}}{g} a_x \cdot\right)^2 + \left(\left(k_{w.z} \cdot S_{plan} \cdot V_z^2 + \frac{G_{QLTM}}{g} a_z\right)\Big|_{F_{Tz} > G_{QLTM}} + \min(F_{Tz}, G_{QLTM})\right)^2, \quad (5)$$

where:

F_T, F_{Tx}, F_{Tz} – thrust and its coordinate components, respectively, N;

$P_{w.x}$ – wind resistance to the horizontal motion, N;

$P_{j.x}$ – force of resistance to horizontal acceleration, N;

$P_{w.z}$ – wind resistance to the vertical motion, N;

$P_{j.z}$ – force of resistance to vertical acceleration, N;

$P_g = G_{QLTM}$ – a part of the vertical component of thrust used to neutralize the gravity of loaded QLTM being transported, N;

V_x – current velocity of QLTM longitudinal (course) motion, m/s;

G_{QLTM} – weight of QLTM (loaded or unloaded as the case may be), N;

$k_{w.x}$ – horizontal (longitudinal) wind shape coefficient, N·s²/m⁴;

S_{front} – frontage area of QLTM, m²;

V_w – longitudinal velocity of QLTM relative to the wind (in the present study, $V_w = V_x$), m/s;

g – gravitational acceleration, m/s²;

a_x – longitudinal acceleration of loaded QLTM, m/s²;

$k_{w.z}$ – vertical wind shape coefficient, N·s²/m⁴;

S_{plan} – area of QLTM in plan view, m²;

V_z – vertical motion velocity of QLTM, m/s;

a_z – vertical acceleration of QLTM, m/s².

It should be noted that $G_{QLTM} = G_{QLTM.0} + G_c$, where $G_{QLTM.0}$ is the weight of unloaded QLTM and G_c is the weight of transported cargo with the package.

Equation (5) represents a generalized expression of QLTM force balance that comprises all typical cases of QLTM operation:

1. initial rest mode (lashing) of cargo, $F_{Tz} = 0$;
2. transition mode of partial hovering of cargo, when $0 < F_{Tz} < G_{QLTM}$;

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3. boundary mode – with zero contact between cargo and the bearing surface (without QLTM breakoff), when $F_{Tz} = G_{QLTM}$;
4. QLTM vertical breakoff mode, when $F_{Tz} > G_{QLTM}$;
5. QLTM flight mode (at $F_{Tz} > G_{QLTM}$);
6. mode of vertical descent to the bearing surface;
7. mode of final fixation of cargo.

The use of equation (5) is associated with particular specifics:

- the term of equation "min(F_{Tz}, G_{QLTM})" represents a force to overcome gravity created by the weight of loaded QLTM: partially – when at $F_{Tz} \le G_{QLTM}$ it is not physically possible for the unit to go upwards, or at $F_{Tz} > G_{QLTM}$, when gravity is overcome completely, it is possible for QLTM to break off the bearing surface due to the remaining force $R_{FTz} = F_{Tz} - G_{QLTM}$;
- equation (5) does not take into account the vertical movement of QLTM when the value F_{Tz} changes in cases of motion 1)–3), which (though insignificant) can occur because of the deformation of tires or suspension of an individual delivery vehicle, or soil flexibility. Vertically oriented speed and acceleration actualized in this case will be massively smaller than the speed V_z and acceleration a_z at QLTM breakoff with $F_{Tz} > G_{QLTM}$ – therefore, in case of adequate substantiation, we can neglect those values.

When considering force balance in uniform steady motion of loaded QLTM close to the bearing surface but without breakoff (i.e. at $F_{Tz} \approx G_{QLTM}$) (mode 3), it is possible to use the following reduced (in relation to equation (5)) equation:

$$F_T^2 = F_{Tx}^2 + F_{Tz}^2 = (P_{w.x})^2 + (P_g)^2 = (k_{w.x} \cdot S_{front} \cdot V_x^2)^2 + (F_{Tz})^2. \quad (6)$$

Let us further focus on this option of force balance. Equation (6) is implicit with regard to $x = F_{Tx}$, $z = F_{Tz}$, $y = V_x$ arguments.

In case of calculation studies, it may be more convenient to use explicit equations with regard to the indicator under consideration.

Implicit equation (6) can be reduced to the explicit form with regard to F_{Tx}:

$$F_{Tx} = (k_{w.x} \cdot S_{front} \cdot V_x^2). \quad (7)$$

Equation (6) can be reduced to the explicit form with regard to F_{Tz}:

$$F_{Tz} = G_{QLTM} + \frac{k_{w.x} \cdot S_{front} \cdot V_x^2 - F_{Tx}}{}. \quad (8)$$

Equation (6) can be reduced to the explicit form with regard to V_x:

$$V_x = \sqrt{\frac{F_{Tx}}{k_{w.x} \cdot S_{front}}}. \quad (9)$$

The following can be written for the longitudinal acceleration of QLTM in the mode of full hovering (at $F_{Tz} = G_{QLTM}$):

$$a_x = \frac{g}{G_{QLTM}}(F_{Tx} - k_{w.x} \cdot S_{front} \cdot V_x^2). \quad (10)$$

The maximum possible longitudinal velocity of hovering QLTM can be determined by setting $a_x = 0$:

$$V_{x.\max} = \sqrt{F_{Tx} / k_{w.x} \cdot S_{front}}. \quad (11)$$

The longitudinal acceleration at the initial moment of longitudinal motion of hovering QLTM can be determined by setting $V_x = 0$:

$$a_x = \frac{F_{Tx} \cdot g}{G_{QLTM}}. \quad (12)$$

The following can be written for the vertical acceleration of QLTM (at $F_{Tz} > G_{QLTM}$):

$$a_z = \frac{g}{G_{QLTM}}(F_{Tz} - G_{QLTM} - k_{w.z} \cdot S_{plan} \cdot V_z^2). \quad (13)$$

Setting $V_z = 0$, it is possible to calculate the vertical acceleration at the initial moment of QLTM ascent:

$$a_z = \frac{g}{G_{QLTM}}(F_{Tz} - G_{QLTM}) \quad (14)$$

The analysis based on equations (3)…(14) can be complemented with corresponding graphical models. The author used Maple software to program the mentioned equations with different graphical representations.

Numerical example. Results

For a numerical example, the author used hypothetical QLTM with own weight $G_{QLTM.0}$ = 30 kN (Container spreaders, 2018, Alfa Group. Spreader for 20-feet containers, 2019), intended to transport standard loaded 20-feet containers with weight G_c = 240 kN, i.e. G_{QLTM}= 270 kN. Let us assume that the QLTM structure represents a container spreader with a QE. The loaded QLTM also has the following characteristics: $k_{w.x}$ = 0.6 N·s²/m⁴; S_{front} = 8 m²; $k_{w.z}$ = 0.9 N·s²/m⁴; S_{plan} = 15 m² (the initial data are substantiated in other papers (Kotikov, 2018d, 2019a, 2019b)).

Let us also assume that the loaded QLTM moves along a simple rectilinear trajectory: 1) vertical ascent to a height of 40 m (maximum height for existing ship-to-shore cranes (Sagizly, 2005)) with constant acceleration; 2) horizontal transportation for a conventional distance of 500 m: with constant acceleration – constant motion – with constant deceleration; 3) vertical descent to a conventional height of 0 m with constant deceleration.

1. Vertical acceleration is conditioned by the fact that the value of vertical thrust exceeds the QLTM weight

(i.e. 280 – 270 = 10 kN): $a_z = \frac{g}{G_{QLTM}}(F_{Tz} - G_{QLTM})$ =

9.8 (280 – 270)/270= 0.363 m/s² (which can be accepted). This is acceleration at the initial moment when V_z = 0. Then the time required for the ascent to a height of 40 m is as follows: t = sqrt(2h/a_z) = sqrt(2*40/0.363) = 14.85 s.

The vertical speed at the moment of approximating 40 m height is as follows: V_z= sqrt(2a_z*h) = sqrt(2*0.363*40) = 5.4 m/s.

Let us calculate the value of wind resistance at this speed:

$P_{w.z} = k_{w.z} \cdot S_{plan} \cdot V_z^2$ = 0.9 N·s²/m⁴ * 15 m² * 29 m²/s² = 391.5 N = 0.391 kN. Thus, we obtain a rather small value (4%) (when compared with the excess vertical thrust). Therefore, we can neglect wind resistance at such QLTM speeds.

2. The horizontal motion at the section of 500 m comprises the following stages: acceleration – steady motion at a set speed (let us set the speed at 10 m/s) – deceleration.

Acceleration:

$$a_x = \frac{F_{Tx} \cdot g}{G_{QLTM}} \cdot$$ = 74,000 N * 9.8 m/s² /27,000 N = 2.69 m/s².

Acceleration time to reach the set speed of 10 m/s: t = v/ax = 10/2.69 = 3.72 s.

Acceleration distance: $S = v^2/2a_x$ = 100/(2*2.69) = 18.59 m.

If we take the value of deceleration as –2.69 m/s², then the time and distance will be the same as in case of acceleration, and the distance of uniform motion will be as follows: 500 – 2*18.59 = 463.82 m. The time will be as follows: 463.82/10 = 46.38 s.

In this case, it is necessary to consider wind resistance overcoming. When the vertical component of thrust F_{Tz} = 270 kN is maintained, the horizontal component $F_{Tx} = k_{w.x} \cdot S_{front} \cdot V_x^2$ = 0.6 * 8 * 100 = 480 N = 0.48 kN shall be ensured. This is shown in Figure 3b.

3. Vertical descent of the QLTM: let us assume that the QLTM descends in a mirror-like manner with respect to the ascent, with an acceptable acceleration of –0.363 m/s². It should be noted that in this case the F_T thrust characteristic will differ from the thrust during the ascent. As acceleration a_z is directly proportional to the difference (F_{Tz} - G_{QLTM}), then instead of excess, deficiency shall be used to obtain the same value of G_{QLTM} weight, i.e. (F_{Tz} - G_{QLTM}) = –10kN, and then F_{Tz}= 270 kN – 10 kN = 260 kN.

Thus, the total time required for the delivery of cargo from a consolidating terminal aboard a container ship will amount to 14.85 + 3.72 + 46.38 + 3.72 + 14.85 = 83.52 s.

Figure 2 shows a trajectory of the thrust vector (its tip) to ensure QLTM motion along the trajectory described in the numerical example in coordinates $x = F_{Tx}$, $z = F_{Tz}$ $y = V_x$. Here, the dark-blue surface is a surface of maximum thrust FTmax, and the pink surface is a level of weight G_{QLTM}.

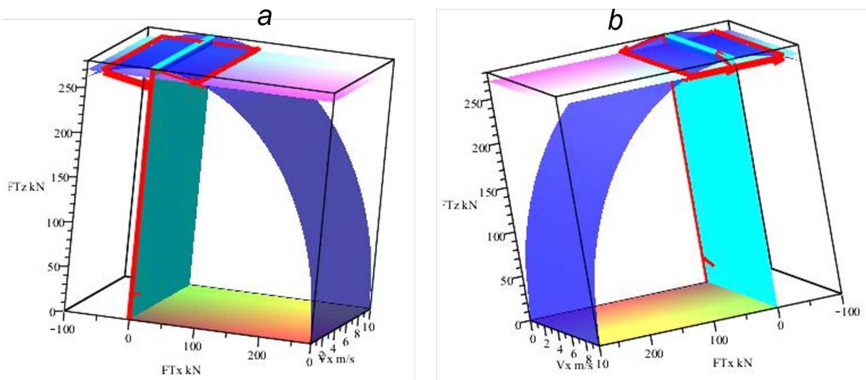

Figure 2. Vector tip trajectory (red line) by phases of QLTM motion: a) view from the side of low speeds; b) view from the side of high speeds.

The analysis can be facilitated by the detalization of the specific features, implemented graphically by changing the range of the arguments presented and their scale (Figure 3).

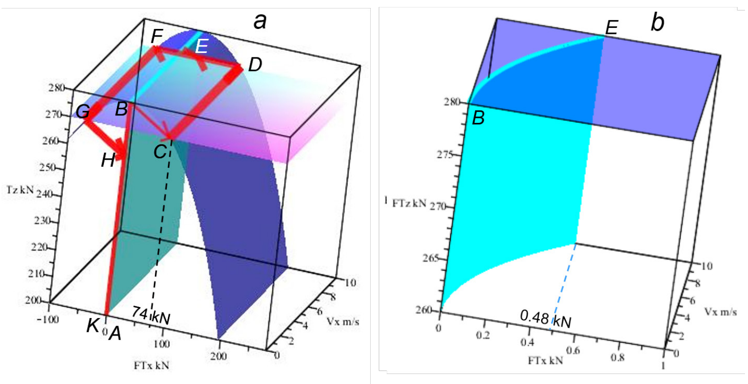

Figure 3. Detalization of the specific features of thrust vector generation to ensure motion along the rectilinear trajectory in the numerical example: a) vector changing by phases of QLTM motion; b) surface of wind resistance to horizontal QLTM motion (blue surface).

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Thrust vector movement by phases and characteristic points of the trajectory is as follows: *A* – QLTM start position; *B* – ascent phase; *BC* – vector switching to horizontal acceleration; *C* – start of horizontal motion; *CD* – longitudinal acceleration to 10 m/s; *E* – steady motion with a speed of 10 m/s; *EF* – vector switching to deceleration; *FG* – longitudinal deceleration to 0 m/s; *GH* – vector switching to descent; *H* – descent phase; *K* – QLTM final position.

Discussion

Despite the fact that the example of QLTM motion along the rectilinear trajectory with sudden changes in the nature of motion (switching from vertical motion to horizontal and vice versa, rough thrust vector switching, and, as a consequence, rough changes in QLTM accelerations) is rather simple, in the author's opinion, it is possible to get an overview of QLTM motion.

Sure enough, QLTM motion can be more complex and elegant, with inclined ascents and descents, maneuvering over the facilities of a terminal, consideration of the difference between accent and descent stages as well as their specifics (in contrast with their "mirror-like" nature).

In case of mass use of QLTM, dispatching can be performed with the distribution of trajectories in a 3D space, where all QLTM units are unified by a single purpose (e.g. fast loading of a ship with containers).

In some cases, existing lift-and-transport machines can be replaced by transport machines equipped with QEs (QLTM), and thus it will be possible to make the area of traditional lift-and-transport machinery movement available. Lifting machines (cranes, etc.) can also be replaced by QLTM. Moreover, several types of lift-and-transport machines as well as transport machines used at warehouses to handle cargo can be replaced by unified QLTM (UQLTM) providing continuous transportation of cargo (without any transshipment using different types of vehicles). For instance, a container located at an open container port can be transported from a consolidated terminal (or even from a vehicle or railway platform) directly to the hold/deck of a container ship. A consolidated terminal becomes available, and a new work method as well as the use of a 3D space of a port will make it possible to significantly increase cargo flow.

All aspects mentioned need to be elaborated in further studies.

Conclusions

According to the results of the study, given the actual realization of the idea and implementation of the principles of non-fuel energy production based on the extraction of energy from the physical vacuum, the presented QLTM concept is rather sound.

In the author's opinion, programming and graphical tools of modern Maple software can ensure future calculations, studies and design activities related to QLTM.

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УНИВЕРСАЛЬНАЯ КВАНТОВАЯ ПОДЪЕМНО-ТРАНСПОРТНАЯ МАШИНА

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Аннотация.

Введение. Возможность извлечения энергии из физического вакуума, открывающаяся с перспективой освоения положений теории Суперобъединения Леонова, изменит механику движения и характер использования подъемно-транспортных средств, при установке на них квантовых двигателей (КвД). **Цель.** Формирование концепции и рабочей гипотезы функционирования комплексной (unified) ПТМ с квантовой тягой – UQLTM. **Методы.** Разложение вектора траста на ортогональные компоненты. Использование обобщенного уравнения силового баланса и его модификаций. Определение характерных режимов QLTM. 3D-моделирование силового баланса с разверткой по скорости. Программирование 3D моделей силового баланса в ППП Maple. Построение образов поверхностей сопротивлений и динамики вектора траста. Расчетные и графоаналитические исследования. **Результаты.** Представлены результаты вычислений с визуализацией на конкретном примере переноса контейнера с накопительной площадки в трюм морского контейнеровоза посредством QLTM. **Обсуждение.** Существующие ПТМ могут быть заменены транспортирующими машинами с КвД в их конструкциях (QLTM), что позволит высвободить полосу движения привычного ПТМ. Подъёмные машины также могут быть заменены QLTM. Более того, несколько типов ПТМ и ТМ, используемых на складах в последовательности технологических операций обработки конкретного груза, могут быть заменены одним универсальным UQLTM, осуществляющим непрерывное перемещение груза, без перегрузки с одного вида ТС на другой.

Ключевые слова

Квантовый двигатель, квантовая тяга, квантовая подъемно-транспортная машина, силовой баланс.

DIGITALIZATION AS A FACTOR OF RISK MANAGEMENT IN A RESEARCH AND PRODUCTION COMPANY IN THE FIELD OF MOTOR VEHICLE EXAMINATIONS

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Abstract

Introduction: The basic level of industry risk in the field of expert services remains unacceptably high due to the effect of a significant number of various factors. **Purpose of the study:** The authors study the influence of enterprise risk factors upon production digitalization in the field of expert services. **Methods:** The authors used content analysis for the software life cycle to assess the discount period for the net operating income of an enterprise upon the introduction of a system to evaluate the quality of developed software and switching to short iterations regarding sales. **Results:** Software implementation in the field of motor vehicle examination not only significantly improves the technical and economic performance of an expert organization but also complies with standards of business conduct in the information society in general.

Keywords

Risk management, use of online programs for expert examination of road accidents, digitalization, special software.

Introduction

Currently, a strong dependence on market conditions represents a major challenge for any company operating in the field of expert services. There are numerous management methods that make it possible to solve the challenges of companies operating in the field of independent forensic expert examination, and risk management represents their integral part. It should be noted that the basic level of industry risk in this economic segment remains unacceptably high due to the effect of a significant number of various factors such as the profitability level, cost of entrance to the market and exit from it, paying capacity of counterparties, weak market position of a new company, etc. Risk factors of companies operating in the field of expert services are described in various publications (Dearstyne, 2001; Strelets, 2008; Vorobyova, 2014) but the following key parameters shall be distinguished:

I. In terms of industry risks:

- fast technological changes in the field of expert services, which can result in increased costs for examination (including those related to examination quality improvement);
- a large number of available expert analysis methods and/or their fast implementation throughout the entire period of expert organization activities;
- high barriers to exit from the market: a small number of potential buyers of new developments due to high prices, strong competition, low profitability, and other factors;
- a significant influence of state authorities on the development of the expert industry: support of government-owned expert institutions (including the provision of a legislative framework, etc.).

II. In terms of management risks:

- lack of a clear strategic development direction, implementation of a risky investment policy, high operational risk, etc.

III. In terms of business risks:

- use of counterfeit software;
- lack of economic position analysis.

The consolidated industry risk associated with the activities of a company operating in the field of motor vehicle and examination can be attributed to the following types of economic activity (according to the Russian National Classifier, or OKVED): 72 (scientific research and development), 74 (other professional, scientific

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and technical activities). According to the data of a risk analysis and management program located on the www.checkbusiness.net website, these activities are characterized by the following consolidated industry risk indices (based on more than 50 factors):

- as of 01.04.2019, the industry risk index for 72 OKBED was 3.717532 out of 5, i.e. the industry is high-risk;
- as of 01.04.2019, the industry risk index for 74 OKBED was 3.6146104 out of 5, i.e. the industry is also high-risk.

Purpose of the study

When an indicator for the availability of proprietary (or franchise) software developments is introduced in the matrix of industry risk indices, some factors cease their adverse effect and the consolidated industry indices for a particular organization decrease to 1.993211 and 2.7544 for 72 and 74 OKVED, respectively, moving to the category of medium-impact industry risks. These indicators can be achieved by changes in the rating of individual industry risk factors. For instance, in the “profitability in the industry” group, availability of proprietary software and databases decreases the value of the “strong competition in the industry” consolidated factor by 1 point, the value of the “availability of monopolists in the market or its individual segments” consolidated factor will be equal to 1, and the value of the “availability of substitutes” factor will be equal to 0. If proprietary methodological developments and software are available in a company, an issue of assessing the life cycle of intellectual deliverables is included in the process of enterprise risk management.

Methods

The impact of the sales decrease factor in the presence of expert methods and software reduces proportionally to the level of program utilization process scalability and availability of programs to users. The impact of the factor of fast technological changes in the industry also significantly reduces to the minimum value. In the “conditions of entrance to the market and exit from it” group of industry risk factors, the impact of such key factors as “lack of qualified experts in the industry”, “significant influence of state authorities on industry development”, and “high barriers to exit from the market for investors” reduces. The impact of the group of factors describing the influence of competitors on the target audience also significantly reduces. Therefore, external market conditions become more favorable for the research and development area, and the consolidated risk index calculated within the framework of the rating model reduces to the safe value. This confirms a thesis by well-known American economist R. Coase (Coase, 1995) who asked why firms exist. His answer is as follows: a firm makes it possible to reduce transaction costs of market coordination. While the “spontaneous order” makes it possible to save transaction costs in large groups, hierarchy provides the same result in small groups, i.e. within the company organization. But due to modern information technologies, it is possible to reduce transaction costs in many sectors almost to zero (Strelets, 2008).

Reduction of the management risk factor weight in an expert organization when passing the barrier of venture investments in the development of software/databases or the procurement of franchises is conditioned by the fact that the software process cycle in the market of R&D services ceases to be unstructured and becomes associated with the software update frequency. In turn, intellectual services start to be considered as operations related to the use of software, i.e. the concept of “quality” is introduced, which is used as “the degree to which a set of inherent characteristics fulfills requirements” as defined in ISO 9000:2000 Quality management systems – Fundamentals and vocabulary. It is interesting to note that in this case such “degree” takes on the role of product limitation, bringing the field of expert services in the area of motor vehicle examination to the software industry, which is currently implemented in all expert activities management areas – from requirements management (“quality attribute” as a category of non-functional requirements) to testing of new technologies (such metrics as MTTF (mean time to failure) and MTBF (mean time between identified failures), etc.) (ITMO, 2016). It can be concluded that the simplification of interaction between the consumer and the manufacturer due to the capabilities of special software predetermines shift of the consumer interests from the long-term period to the short-term. Basically, it means the formation of a new organization essence within the framework of so-called “information profitability”, which means the ability of companies and other organizations optimally and systematically use information for achieving strategic goals as a way of integrating information skills of the company with those advantages that are provided by electronic forms of exchange (Dearstyne, 2001).

The lack of economic position analysis in management accounting is typical for all medium-sized organizations. However, this is one of the key factors in risk management analysis. Using an example of cost management in an expert organization, we will demonstrate a method of gaining additional profit that can be used to develop proprietary software and a database to enter the area of moderate or low risks. For instance, accounting of Net Operating Income (NOI) makes it possible to analyze whether opportunities for investing using internal (and not borrowed) reserves are available, which significantly affects payment risk factors and, as a consequence, the financial stability of an organization (Vorobyova, 2014). NOI for the sphere of expert services in the field of forensic expert examination can be calculated by the following equation:

$$NOI = C_e \cdot N \cdot 20 - C_r - O_{ex} - C_{tax} \quad (1)$$

where: C_e is the average cost of one examination, C_r is the cost of renting, Oe are overhead expenses, C_{tax} are taxes, N is the number of examinations per day.

The value of an expert organization can be calculated for the period of investing in the development of proprietary software and a database using the following equation:

$$NVP = \sum_{t}^{T} 1 \frac{Ct}{(1+r)^t} \quad (2)$$

where: NVP is the business value, C_t is NOI from the first to the last applicable period, r is the discount rate. It should be kept in mind that the key task is to determine a method to assess the life cycle of intellectual deliverables, to which deprecated normative methods (such as program- and goal-oriented planning, inventory accounting, probabilistic models for asset retirement) cannot be applied. In this case, so-called content analysis in that knowledge area where software is used comes to the forefront, i.e. management activities are transferred to the field of linguistic studies related to existing computer ontologies and work with AI (Gritz, 2018).

Let us consider an example of calculating the business value for five conditional periods with regard to one of the Saint Petersburg expert organizations. The calculation was used for two cases: without the development/use of software or a database, with the development/use of software and a database. In case an expert continues to perform calculations manually, the business value amounts to RUB 25,551,790 (Table 1).

Table 1. Calculation of the business value by NOI discounting

NOI	8,544,000	8,544,000	8,544,000	8,544,000	8,544,000
Cd	0.833333	0.694444	0.578704	0.482253	0.401878
Income	7,120,000	5,933,333	4,944,444	4,120,370	3,433,642
Business value					25,551,790

In case an expert ensures process automation, the business value amounts to RUB 39,045,432 (Table 2).

Table 2 .Calculation of the business value by NOI discounting

NOI	13,056,000	13,056,000	13,056,000	13,056,000	13,056,000
Cd	0.833333	0.694444	0.578704	0.482253	0.401878
Income	10,880,000	9,066,667	7,555,556	6,296,296	5,246,914
Business value					39,045,432

The obtained economic effect in the form of business value increase by RUB 13,493,642 makes it possible to make investments in the first stages of developing proprietary software and databases, not relying on borrowed funds. The simplified model of calculations shown for clarity demonstrates business value increase by 52.8% at the reduction of expert organization risk factors. Due to the development and implementation of online programs for road accident analysis, located on the accident.zone and dtpmaster.ru landing pages (Figures 1, 2), it became possible to reduce the time required for examinations by 50%, make additional labor and financial resources available, decrease internal transfers when several qualified experts were needed.

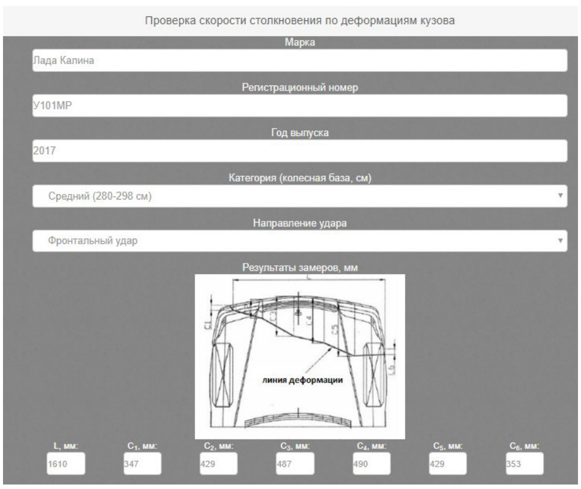

Figure 1. Module for the calculation of car speed (Vc) loss in relation to body deformation in the dtpmaster.ru environment (Tul'kin, 2015).

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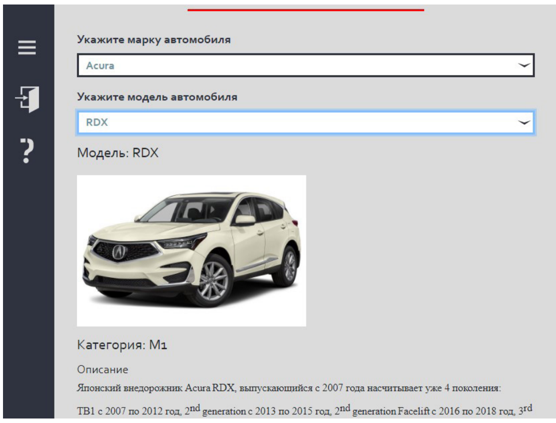

Figure 2. Car directory in the accident.zone environment.

To manage software development risks, the following basic indicators of the earned value method can be used:

- cost variance (CV). This indicator makes it possible to answer the following question: "Is the project within or beyond the budget being determined by an increase in variable expenses of the expert organization for the period of investing in the development of software and a database?"

$$CV = EV - AC \quad (3)$$

where: EV is the investment earned value, AC is the actual cost.

The cost variance can also be expressed in percent by the following equation:

$$CVp = 100 \times (EV - AC)/EV = 100 \times CV/EV, (\%) \quad (4)$$

- schedule variance (SV).

$$SV = EV - PV \quad (5)$$

Despite the fact that the estimates obtained using this method describe the existing situation regarding software/database development more adequately, they still require a clear understanding of planned expenditures for each stage of development and its timelines. Rational planning of investments, which in this case affect variable expenses, can also be assessed at each stage within the framework of risk management, thus making it possible to manage business risks. Figure 3 shows a software/database quality checklist according to ISO 9126.

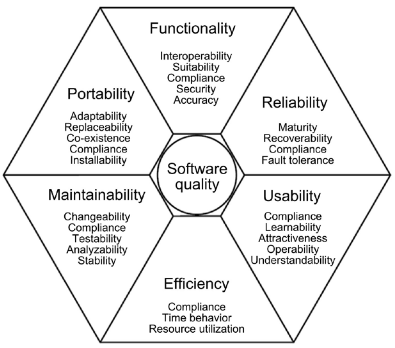

Figure 3. Software quality characteristics and attributes according to ISO 9126.

If complex software is developed, then relative independence of task sets matters as it makes it possible to develop and implement those in parallel or in sequence depending on the financial possibilities of an organization. The design of individual sub-tasks simplifies system adaptation to conditions of a particular enterprise (Polozov, 2010).

The functional aspect of risk management includes quantitative and qualitative risk assessment, planning and implementation of actions to prevent possible negative consequences, control of their execution, and constant monitoring for the purposes of identifying new risk areas (Vorobyova, 2014). All this is possible if modern risk management systems (also represented by software) are used. For instance, using the software solution mentioned above, it is possible to make instantaneous calculations for all risk types and factors in any expert organization, and score the business (Figure 4).

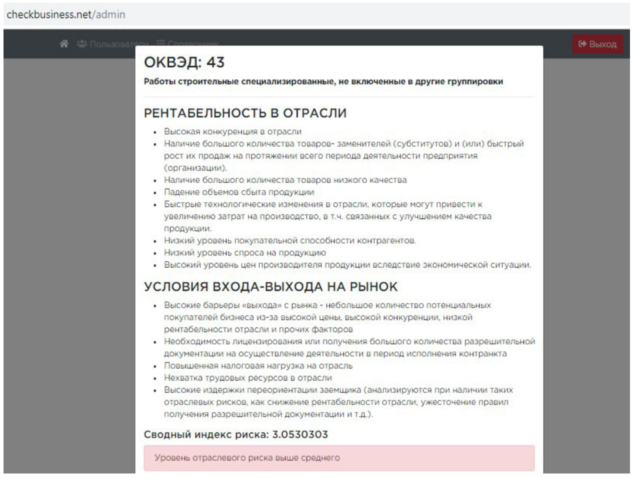

Figure 4. Operation of the organization risk management program located on the checkbusiness.net website (example).

Results

The influence of software development and implementation on internal factors associated with business activities is conditioned by processes occurring during the manufacturing and sales of products and can, in turn, affect business results. American economists Kaplan and Norton made several assumptions, based on which it is necessary to build company operations and management under conditions of business informatization. In particular, they pay attention to requirements for business process flexibility and integration when new technologies are created, greater customer segmentation (when diversified products of the information society replace standard products of the industrial society), business scalability, requirements to reduce the life cycle of a product (e.g. software product) as a result of continuous innovations (competitive advantages at one of the stages of the product life cycle do not guarantee that the product will maintain the leading position at the next stage of technological transformations) (Kaplan and Norton, 1996).

Thus, software development and implementation in the field of motor vehicle examination not only significantly improve the technical and economic performance of an expert organization but also comply with standards of business conduct in the information society in general.

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ЦИФРОВИЗАЦИЯ КАК ФАКТОР УПРАВЛЕНИЯ РИСКАМИ НАУЧНО-ПРОИЗВОДСТВЕННОЙ ОРГАНИЗАЦИИ НА ПРИМЕРЕ АВТОТЕХНИЧЕСКИХ ЭКСПЕРТИЗ

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Аннотация

Введение. Учет базового уровня отраслевого риска в отрасли экспертных услуг, остается недопустимо высоким вследствие влияния существенного количества факторов. **Цель исследования.** Изучение влияния факторов риска предприятия при цифровизации производства продукции в экспертной деятельности. **Методы.** Использование контент анализа жизненного цикла ПО для расчета дисконтируемого периода чистого операционного дохода предприятия при введении системы оценки качества, разрабатываемого ПО и переходе на короткие итерации продаж. **Результаты.** Внедрение ПО в области автотехнических экспертиз не только существенно улучшает технико-экономические показатели экспертной организации, но и соответствует нормам ведения бизнеса в новом информационном обществе в целом.

Ключевые слова

Управление рисками, использование онлайн программ для экспертизы дорожно-транспортных происшествий (ДТП), цифровизация, специальное программное обеспечение.