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TEXNIKA FANLARI DOKTORI, PROFESSOR MIRAXMEDOV MAXAMADJON MIRAXMEDOVICH TAVALLUDINING 80 YILLIGIGA BAG‘ISHLANGAN “SAMARALI QURILISH MATERIALLARI, KONSTRUKSIYALARI VA TEXNOLOGIYALARI” MAVZUSIDAGI XALQARO ILMIY-AMALIY KONFERENSIYASI ILMIY ISHLARI TO‘PLAMI

Toshkent davlat transport universiteti RAASN akademigi, O'zbekistonda xizmat ko'rsatgan yoshlar murabbiyi, texnika fanlari doktori, professor Miraxmedov Maxamadjon Miraxmedovich tavalludining 80 yilligiga bag'ishlangan, ilmiy ishlar to'plami nashr etilishi ko'zda tutilgan «Samarali qurilish materiallari, konstruksiyalari va texnologiyalari» mavzusidagi Xalqaro ilmiy-amaliy konferensiyani o'tkazishni rejalashtirmoqda.

M.M. Miraxmedov kompozitsion qurilish materiallarining polistruktura nazariyasini rivojlantirishga salmoqli hissa qo'shgan. Uning qurilish materialshunosligi sohasidagi ilmiy hissasi e’tirofi sifatida 1995-yilda Rossiya arxitektura va qurilish fanlari akademiyasining (RAASN) xorijiy a’zosi etib saylangan. M.M. Miraxmedov 6 ta monografiya, 200 dan ortiq ilmiy maqolalar va 25 ta ixtiroga mualliflik guvohnomalari muallifidir.

Ushbu konferensiyaning asosiy maqsadi - qurilish materialshunosligi, bino va inshootlarni loyihalash va qurilish sohasidagi ilmiy tadqiqotlar natijalarini, shuningdek, muhandislik ta’limini takomillashtirish yo'llarini muhokama qilishdan iborat.

Konferensiya ishida ishtirok etish uchun oliy o'quv yurtlari va ilmiy tadqiqot institutlari olimlari, O'zbekiston Respublikasi va xorijiy davlatlarning ishlab chiqarish vakillari, ilmiy tadqiqotlarda salmoqli natijalarga ega bo'lgan mutaxassislar taklif etiladi.

“Samarali qurilish materiallari, konstruksiyalari va texnologiyalari” mavzusidagi xalqaro ilmiy-amaliy konferensiyaning asosiy yo‘nalishlari quyidagilardan iborat:

1. Resurs va energiya tejovchi qurilish materiallari va texnologiyalari.
2. Atrof-muhitning transport infratuzilmasiga ta’siri va uni himoya qilish usullari.
3. Bino va inshootlarning qurilish konstruksiyalari: hisoblash va loyihalashning zamonaviy usullari.
4. Arxitektura, shaharsozlik va shahar muhitini rivojlantirish.
5. Qurilishni tashkil etishning innovatsion usullari va qurilish jarayonlari texnologiyalari.
6. Transport obyektlarini loyihalash va qurishda raqamli texnologiyalar hamda sun’iy intellekt.
7. Temir yo‘l transporti infratuzilmasi obyektlarini loyihalash, qurish va ekspluatatsiya qilish.
8. Zamonaviy muhandislik ta’limi tizimini takomillashtirish.

Mazkur konferensiya ilmiy hamjamiyatning turli vakillarini bir joyga jamlab, qurilish materialshunosligi sohasidagi zamonaviy muammolar va istiqbollarni muhokama qilish uchun qulay platforma vazifasini bajardi.

Technological Efficiency of Modular Green Roof Systems for Operated Flat Roofs in Nukus Conditions

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Abstract: The paper examines the technological performance of modular green roof systems for operated flat roofs under the climatic and construction conditions of Nukus. The study combined regulatory review, comparative analysis of roof alternatives, functional and organizational modeling, and chronometric observations carried out for the installation of a modular greening system. An operated roof with a total area of 324 m² was taken as the reference object, while detailed timing measurements were performed for a 10 m² installation zone. The average duration of modular installation was 3.52 h per 10 m², and the total labor input was 10.56 person-hours, which corresponds to a rational crew of three workers. Comparative calculations for six constructive-technological alternatives showed that the modular option with 0.5 m modules achieved the best overall result: 167 person-hours and 18 shifts for the full roof, versus 231–233 person-hours and 20 shifts for pedestrian hard-surface alternatives. A system of efficiency indicators was used to separate the labor contribution of the multilayer substructure from that of the greening layer. The results show that the modular solution slightly increases the labor share of the green layer itself, but compensates for this by reducing labor in the supporting roof structure, shortening the work cycle, and improving maintainability.

Keywords: Modular green roof; operated flat roof; labor intensity; technological efficiency; chronometric observation; Nukus; organizational and technological modeling

1. INTRODUCTION

Cities in arid regions do not have the luxury of treating the roof as a passive enclosure only. In Nukus, where dense development, dust-laden winds, sharp summer overheating, and limited land resources act at the same time, the roof increasingly becomes a reserve urban surface. Yet the question is not simply whether a roof can be greened. The more practical question is how such a roof can be built without turning the technology into an expensive and slow construction exercise.

Most published work on green roofs focuses on thermal behavior, environmental benefits, drainage, or plant selection. Those issues are essential, but they do not fully answer a contractor's everyday concerns: how many operations are needed, which stage concentrates the highest labor input, what crew is rational, and which variant is more manageable during installation and maintenance. This gap becomes especially visible when operated roofs are compared with pedestrian hard-surface roofs and with continuously greened roofs.

The purpose of this study was to substantiate a constructive-technological solution for modular greening of operated flat roofs and to evaluate its efficiency through measured process parameters. The article relies on the final dissertation materials devoted to the technology of constructing roof coverings used together with greening systems and presents them in a compact journal format.

2. MATERIALS AND RESEARCH METHODS

The research combined several mutually connected methods. First, the normative and scientific background of green construction, operated roofs, and roof retrofitting was reviewed. Second, six alternative constructive-technological variants were compared: two pedestrian roof solutions (V1A, V1B), two continuously greened roof solutions (V2A, V2B), and two modular green roof solutions (V3A, V3B). Third, the process structure of modular installation was decomposed into individual operations and formalized through organizational and technological modeling.

Chronometric observations were then carried out for a 10 m² installation zone of a modular greening system. The measured operations covered marking, placement of adjustable supports, slope correction, fixation of connectors, laying of the grating deck, module anchoring, and filling with substrate and planting material. The study used average duration, labor input, crew composition, and stability of the time series as the main process indicators.

For the full-scale comparison of roof alternatives, an operated flat roof with an area of 324 m² was accepted as the reference object. This made it possible to compare not only local installation operations, but also the labor contribution of the multilayer roof substructure and the upper operating or greening layer. The evaluation logic intentionally separated these two groups because in practice they behave differently: some solutions reduce labor in the upper layer but overload the substructure, while others do the reverse.

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Technological framework for the modular green roof

The proposed modular roof system is built around adjustable supports, a grating deck, detachable modules, geotextile containment, substrate, and vegetation. This arrangement was selected for three reasons. First, it protects the waterproofing layer from direct repeated mechanical stress. Second, it creates a technical gap where irrigation lines and service elements can be placed without dismantling the whole roof build-up. Third, it allows damaged modules to be replaced locally, which is an important practical advantage for roofs exposed to strong sun and wind.

From a construction standpoint, the process is divided into three stages. The first stage forms the working base and the adjustable support system. The second stage creates a stable deck. The third stage installs the greening modules and fills them with substrate and planting material. This staged logic is simple enough for site control, but detailed enough to support chronometric measurement and crew planning.

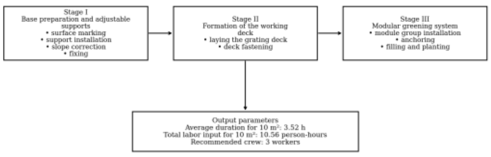

Fig. 1. Staged technological framework for constructing an operated flat roof with a modular greening system

3. RESEARCH RESULTS

The chronometric observations showed that the installation process is not evenly distributed in time. Stage I, where the support system is laid out and adjusted, is the most time-consuming block. Within this stage, the adjustment of support slope takes the largest share because it directly affects future surface stability and water drainage. Stage II is comparatively compact, while Stage III combines medium-duration assembly operations with the physically heavier task of filling the modules.

The sum of the average operation durations reached 211 min, or 3.52 h for 10 m². With a total labor input of 10.56 person-hours, the rational crew size is obtained as:

$$N_z = T_{um} / t = 10.56 / 3.52 = 2.98 \approx 3 \qquad (1)$$

In practical terms, this means one 3rd-grade roofer, one 2nd-grade roofer, and one 3rd-grade green-construction worker. That composition is balanced: the roof specialists carry the accuracy-sensitive operations, while the green-construction worker absorbs the operations connected with module preparation, anchoring, and filling.

Table 1

Average duration and labor input of modular roof installation operations (per 10 m²)

Operation	**Stage**	**Average duration, min**	**Labor input, person-hours**
Surface marking	Stage I	20	1.00
Support placement and gluing	Stage I	22	1.10
Slope adjustment of supports	Stage I	40	2.00
Fastener fixing	Stage I	14	0.70
Laying the grating deck	Stage II	26	1.25
Fixing the grating deck	Stage II	17	0.85
Installing a 4-module group	Stage III	22	1.10
Fixing the module group	Stage III	20	1.00
Filling with substrate and planting material	Stage III	30	1.50

The comparison of constructive-technological variants confirmed that the best local process indicator does not automatically produce the best full-roof result. Pedestrian hard-surface roofs remain relatively straightforward in their upper layer, yet they accumulate significant labor in heavy surface finishing. Continuously greened roofs reduce hard-surface operations, but the arrangement of the greening layer is less flexible in maintenance terms. The modular solutions redistribute work more evenly and reduce the labor intensity of the substructure, especially when smaller modules are used.

Among the six alternatives, V3B—the modular roof with 0.5 m modules—showed the lowest total labor intensity, 167 person-hours, and the shortest work cycle, 18 shifts. This is a strong result because it is achieved not by simplifying the roof function, but by reorganizing the technological chain. The work becomes more segmental, better suited to phased delivery, and easier to maintain after commissioning.

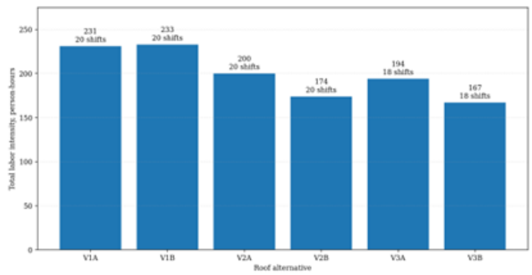

Fig. 2. Total labor intensity of the compared roof alternatives; duration is shown above the bars

Table 2

Comparative labor intensity and duration of constructive-technological roof alternatives

Variant	Description	Stage II: roof substructure, person-hours	Stages III+IV: upper layer and greening, person-hours	Total labor intensity, person-hours	Duration, shifts
V1A	Pedestrian roof, variant 1	86.6	45.0	231	20
V1B	Pedestrian roof, variant 2	89.3	45.0	233	20
V2A	Continuously greened roof, variant 1	71.6	29.1	200	20
V2B	Continuously greened roof, variant 2	51.8	22.9	174	20
V3A	Modular green roof, module diameter 1.0 m	59.6	35.1	194	18
V3B	Modular green roof, module diameter 0.5 m	36.6	31.1	167	18

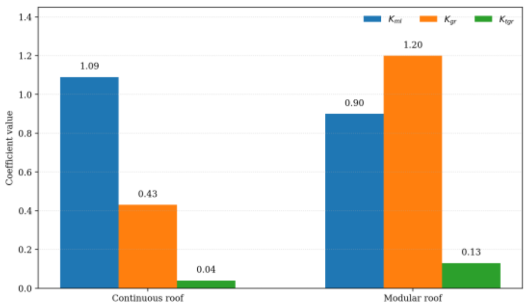

Fig. 3. Comparison of the efficiency indicators for the continuous and modular green roof solutions

Formalized efficiency assessment

To avoid a one-sided reading of total labor intensity, the assessment used three coefficients. The first describes the labor intensity of the multilayer roof structure, the second isolates the labor of the greening system, and the third shows how large the labor share of the greening layer is within the entire roof technology.

$$K_{ml} = Q_{ml,i} / Q_{ml,av} \quad (2)$$

$$K_{gr} = Q_{gr,k} / Q_{gr,av} \quad (3)$$

$$K_{tgr} = Q_{gr,k} / (Q_{ml,i} + Q_{gr,k}) \quad (4)$$

For the continuously greened roof, the coefficients were obtained as 1.09, 0.43, and 0.04. For the modular roof, the corresponding values were 0.90, 1.20, and 0.13. These values deserve a careful reading. The modular system does demand more labor in the greening layer itself, which is why the greening coefficient rises above one. At the same time, it reduces labor in the multilayer roof base, which is why the multilayer coefficient drops below one. The overall share coefficient of 0.13 places the modular solution in the acceptable range and shows that the additional work connected with the green modules does not dominate the full technology.

DISCUSSION

For Nukus conditions, this result is more important than a simple reduction in person-hours. A roof technology that is easier to zone, easier to repair, and faster to execute is usually the safer and more durable option in a sharply continental climate. Wind exposure, rapid summer overheating, and the need for flexible irrigation all favor a system in which the roof can be serviced by fragments rather than as one monolithic layer.

This is where the modular approach shows its real strength. It does not eliminate work; instead, it shifts work from wet and difficult-to-correct site operations toward more controllable assembly operations. From the contractor's perspective, that means cleaner sequencing and less technological uncertainty. From the owner's perspective, it means easier replacement of damaged fragments and a more manageable service life.

The comparison also suggests that the main reserve for labor saving is often not in the visible green layer, but in the substructure beneath it. Once this is understood, design decisions become more rational. A seemingly simpler roof may in fact be less efficient if it relies on labor-intensive underlayers or heavy surface finishing.

4. CONCLUSION

1. The modular greening system for operated flat roofs can be organized as a clear three-stage technological process that is suitable for site control, crew planning, and phased execution.

2. Chronometric observations established an average duration of 3.52 h and a total labor input of 10.56 person-hours for a 10 m² modular installation zone, with a rational crew size of three workers.

3. In the full-roof comparison, the modular alternative with 0.5 m modules (V3B) produced the

best integral result—167 person-hours and 18 shifts—outperforming pedestrian and continuously greened alternatives.

4. The efficiency indicators make it possible to distinguish between the labor of the multilayer roof base and that of the greening layer, which leads to a more balanced technological assessment of roof alternatives.

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