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Comparison of the New Type Modular Panel for Green Roofs and Classical Construction of Green Roofs by Stormwater Management

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Abstract. Proper stormwater management is one of the main problems cities today face. In order to understand how to properly manage urban stormwater it is first necessary to construct roofs with new construction methods. The first step for controlling urban stormwater is the construction of green roofs. We already know that the construction of green roofs improves water management in cities. But can we make it better? What will happen if we use the same layers for the green roofs but with a different construction method? This article wants to answer these questions. In this article the two green roofs, differing in the construction method, are compared and contrasted in terms of stormwater management. One of the green roofs was built traditionally, while the other has been built using a new type of modular panel. The article then compares their results during laboratory tests. In the conclusion you can read about measured data from tests and possible solutions and development of solutions to improve green roofs in the future.

1. Introduction

It is observable that the planet is measurably warmer year to year. We are able to prove that the planet's temperature has risen 0.98 °C since 1880, according to scientific data collected by the US space agency NASA. The largest increase in temperature can be observed in the last 35 years. In the long run, it can be seen that the last five years have been the warmest since 1880. [1] In the Czech Republic, data collected by the Czech Hydrometeorological Institute show an even more dramatic increase in temperature, when from the end of the 19th century to the year 2010 there was an increase of temperature about 1.3 °C. [2]

This warming of our surroundings has a direct consequence on us, due to the fact that there is, on average, lower total precipitation during the calendar year than in the past. As a result of lower precipitation, groundwater reserves are being pumped out, which are not sufficiently replenished, and thus we are only contributing to the ever-accelerating spiral of warming and the emergence of the so-called Urban Heat Islands in cities.

From a construction point of view, this issue is very extensive, and there is a very limited amount of opportunities in the construction industry (especially within the structures themselves) to reduce or increase the average temperatures, especially in regards to current construction trends. One option that can be applied to most existing buildings is the construction of green roofs. The very contribution of green roofs with regard to their retention, slowing down the outflow of rainwater into the sewer, the effect of plants in removing pollutants from the air, protection of building structures, or their favorable effect on the temperature in their surroundings has been described many times.

However, the construction of green roofs itself is very complicated, time-consuming, and usually expensive for the public. For this reason, the scientific team led by Ing. Martina Mohapl, Ph.D., and the Faculty of Civil Engineering at Brno University of Technology decided to construct a prototype of a pre-grown panel from elements that are economically available and as environmentally friendly as possible. This prototype was then described in detail and in this article, it will be compared with the classic construction of a green roof. The structures themselves were compared in laboratory conditions on a special roof platform designed for this purpose. The comparison has been made on the basis of the time required to build a flat green roof in a two-member work team and also measure the water retention for these two roof structures. At the end of the article, it is possible to read what the advantages of each of the selected variants are and how it is possible to improve or eliminate possible problems in the following research.

2. Construction of test segment and tested composition of green roofs

Due to the need to eliminate unfavorable weather conditions as much as possible, the influence of unequal floor plan dimensions, slope, and composition of the structure or the height at which the structure would be carried out, it was decided not to test these two structures on real roofs. Therefore, a temporary roof test segment was created on the grounds of the ADMAS research center for testing roof drainage parameters. The test segment was designed so that it was possible to subsequently measure other types of roofs on it. Thanks to the construction, which allows changing the inclination of the test segment with a safe inclination of up to 40 °, it will be possible to measure runoff parameters on this platform for some types of pitched roofs. Especially for those which will be designed as green roofs. The supporting structure of the test segment was created using wooden elements.

The surface of the test segment measures 4000 x 2360 mm. The segment was created by using OSB boards, on which lays an oxidized asphalt waterproofing strip intended for green roofs. It was melted to create a waterproof layer. A drain was set up at the lower edge of the test segment using a conventional rain gutter. From the eaves was then water by implementing testing of the compositions prepared in collecting vessels mounted on a digital weight designed for this purpose. Due to the possibility of placing different compositional variants of flat roofs on the test segment, it was decided to construct four sidewalls with a height of 350 mm. The main sidewall at the gutter was designed to be fixed and the remaining three sidewalls were designed to be removable. Removable sidewalls were implemented mainly due to the construction of flat green roofs. Another important reason was the possibility of revising the roof strata from the sides for the case of using the platform for a longer period of time than our tested time. A geotextile of 300 g/m2 was then attached to the sidewalls and the waterproofing. To prevent the geotextile from breaching or changing its properties, the geotextile was always replaced with a new one after the end of the test of one type of structure. In order to prevent the influence of weather conditions, a roof was set up above the test segment by means of tarpaulin-proofing, so as to prevent the influence of precipitation or drainage of water discharged into the test segment. Construction of an experimental prototype of a pre-grown panel was based on the experience of a scientific team dealing with this issue and at the same time on consultations with professionals implementing flat green roofs. The experimental panel itself was subsequently modified and developed for 4 years to meet the requirements of construction practices for safety and easy handling. At the same time, of course, the panel had to meet the standards for the construction of green roofs and maintain sufficient soil nutrients for the plants that were grown on it. As part of the testing of different types of panels, it was found that panels that were too small in terms of the floor plan were unable to maintain sufficient moisture when grown alone, and pre-cultivation would therefore make no sense as they would have to be subsidized by a large volume of water. Larger panels, on the other hand, lost the ability to be easily manipulated by one or two workers. However, the larger panels showed that they were able to carry even semi-intensive to intense vegetation, but their weight, especially with a fully saturated sample, was too great for a single person. For these reasons, construction was started combining both methods, i.e. a larger prefabricated panel with the maximum possible lightening with the help of an extensive type of green roof. Thus, in the last development phase, the panel itself consisted of a carrier layer formed using an extruded polystyrene XPS board with a height of 100 mm and floor plan dimensions of 1200 x 600 mm. N , and this panel was subsequently formed using layers of hydro accumulation retention boards produced from recycled polyester fibers interconnected with a fiber-meltable material without chemical additives. The selected height of the retention plates was 40 mm, and the floor plan dimensions were the same as the extruded polystyrene. From the given technical parameters, it is possible to state a basis weight of 4000 g/m2 and a maximum water capacity of 29 l/m2. On the retention plate there was then a substrate bag made of packaging material from a 211 g/m2 jute mesh, in which there was a solid structure of laths measuring 48 x 24 mm anchored through the retention plates into the support layer of extruded polystyrene and at the same time forming solid edges for the substrate. The fixed edges had to be designed to prevent deformation or dropping of the substrate from the panel during transport. The height of the substrate in this construction was then 60 mm. The substrate was also provided with a jute cover on the upper side, as can be seen in Figure 1.

Figure 1. Prototype of pre-grown panel

The installation of the roof structure from pre-grown panels was carried out in favorable weather on a sunny day. Nine experimental pre-grown panels were constructed for the area of the tested segment (Figure 2). Based on discussions with experts, it was decided that the panels will not be greened, because sufficient coverage of the panels by the stonecrops would take too long; this problem would, however, not occur in continuous production in larger quantities. At this point, it should be emphasized that in the case of greening the panels, the absorption (retention) capacity of the panels would increase due to the plants used and the panels would also be more compact. Thus, with the presence of plants, the panels would have better technical properties than they actually had during the testing, since the plants were not present. Nine panels were gradually moved from the storage hall (Figure 3) to the test segment. The actual assembly of the roof from pre-grown panels, according to time measurements, took 16 minutes and 12 seconds when it was constructed by two workers.

Figure 2. Experimental panels

Figure 3. Construction of the roofs by the panels

Figure 4. Construction of the traditional green roof

Figure 5. Construction of the traditional green roof without plants

The composition of the green roof was chosen to be almost the same as the composition of the experimental pre-grown panel. The same composition was decided upon mainly due to the objective assessment of the complexity of the structure and its drainage properties. Thus, a layer of retention plates measuring 1200 x 600 mm and 40 mm high was placed on the geotextile layer (Figure 4). Subsequently, the substrate was laid out at the required height using guide rails to maintain a height of 60 mm; those rails were then removed (Figure 5). After a discussion with experts, the roof was left without greenery after construction due to time constraints. The greening itself adds value to the roof in terms of retention and absorption of pollutants, but planting the roof is time-consuming. For this reason, the roof would have a better retention capacity in the case of greenery, and its construction would also take longer. The construction of the traditional extensive green roof took two workers 60 minutes; unlike the construction of a panel roof, we can see a significant amount of time saved due the greening of the roof.

3. Retention measurement for tested compositions

Both compositions were then evaluated for retention using standard precipitation modeling. For the Brno area, the periodicity of rain 1 and the total precipitation of 12.9 l/s.m2 for 15 minutes were calculated. Subsequent measurements of rainwater runoff were performed for 4 hours. Artificial rain was created using 30 misters and 24 water jets, which were evenly distributed by slats over the entire area of the test segment (Figures 6 and 7).

Figure 6. Artificial rain on the roof from pre-grown panels

Figure 7. Artificial rain on the roof

4. Comparison of both types of green roof construction

The first verified comparison was between the time and overall complexity of the constructions. Both compositions were built on a rectangular area of 4000 x 2360 mm without penetrations and edge adjustments using gravel. These were therefore clean areas of large flat green roofs, which for time reasons were not planted with plants. The area of the roof cladding produced in this way was therefore 9.44 m2. Both roof compositions were performed by a pair of workers. The implementation time was then adjusted to a standard hour for one worker per square meter. At the same time, the worst possible variant was considered during the implementation, namely the need to manually unload all materials onto the roof. In Table 1 it is possible to see the implementation time of the roof area using pre-grown panels and in Table 3 the implementation time of a variant of a traditional large green roof is shown. In Tables 2 and 4, it is then possible to compare the implementation time of individual subcomponents of two of the selected compositions.

Table 1. Time of realization of the roof from pre-grown panels

	Area (m2)	Number of workers:	Total time (min.)	Total time for 1 worker	Time for 1 m2 (min)
Roof area:	9.44	2	16.2	32.4	3.43

Table 2. Partial parts of the roof realization from pre-grown panels

	Time (h)	Time (min)	Time for 1 worker	Time for 1 m2 (min)
Laying geotextiles	0.1	6	12	1.27
Laying of pre-grown panels	0.17	10.2	20.4	2.16
			Total	3.43

Table 3. Implementation time of an extensive green roof

	Area (m2)	Number of workers:	Total time (min.)	Total time for 1 worker	Time for 1 m2 (min)
Roof area:	9.44	2	60	120	12.71

Table 4. Partial parts of the implementation of an extensive green roof

	Time (h)	Time (min)	Time for 1 worker	Time for 1 m2 (min)
Laying geotextiles	0.1	6	12	1.27
Laying retention boards	0.3	18	36	3.81
Delivery + substrate distribution	0.6	36	72	7.63
			Total	12.71

A comparison of two green roof structures based on the time required for construction showed that the implementation of the building using pre-grown panels is 3.7 times faster than in the case of a traditional extensive flat green roof. The second monitored variable was the ability to retain rainwater. The test was performed according to standard requirements, where water was released on the roof cladding by an even distribution and subsequently the outflow of water from the roof cladding was monitored for four hours. These drains can be seen in graphs No. 1 and 2. Graph No. 1 (Fig. 8) shows the amount of water flowing out of the roof cladding created by means of pre-grown panels. From the graph, it can be read that the state of saturation of the flat roof, when it is not able to quickly absorb more water and all the excess water leaves the roof into the sewer, occurs after approximately 4 and a half minutes (264 seconds). Subsequently, the water outflow increases sharply and any excess water leaves the roof until the end of a standard rain cycle with a slight delay determined by the need for water to flow through the roof cladding structure. The time at which the water drain begins to settle after 19.8 minutes (1190 seconds). Thus, we can state that in heavy rain, the roof of pre-grown panels can slow down the water outflow by approximately 4 and a half minutes. After 15 minutes, when the standard rain is over, we can observe that 6.238 l of rainwater flowed through the roof formation. After 19.8 minutes, the curve flattens and the rapid rise of the effluent water ends. The water flowing out of the roof cladding in 19.8 minutes from one m2 is equal to 7.485 l. in the structure of the roof panel.

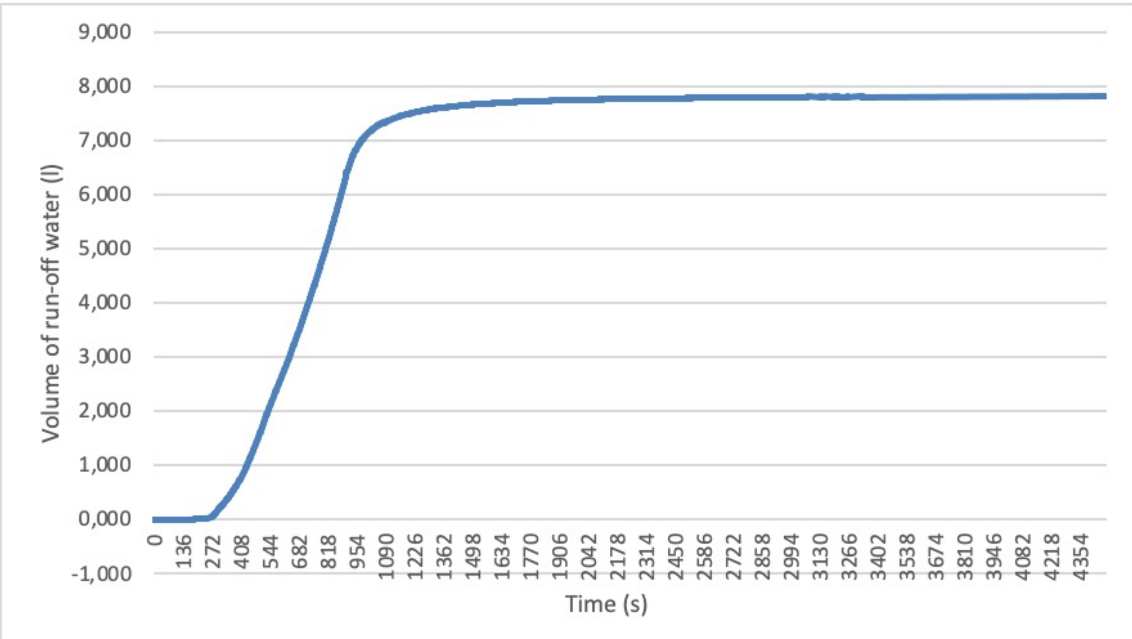

Figure 8. Water drainage using pre-grown panels

In Graph No. 2 (Fig. 9), we can see the results of an extensive green roof constructed through traditional methods. In this composition, the first outflow of water from the roof formation occurs after 4.8 minutes (290 seconds), i.e. about 26 seconds later than in the panel variant. This is followed by a more gradual increase in runoff, where after 15 minutes we can see an overflow of 2.048 l. However, the flattening of the curve is smaller than in the previous variant, and the water drained from the stack increases by one-hundredth of a liter of water in about 5 minutes (300 seconds) until the end of the test.

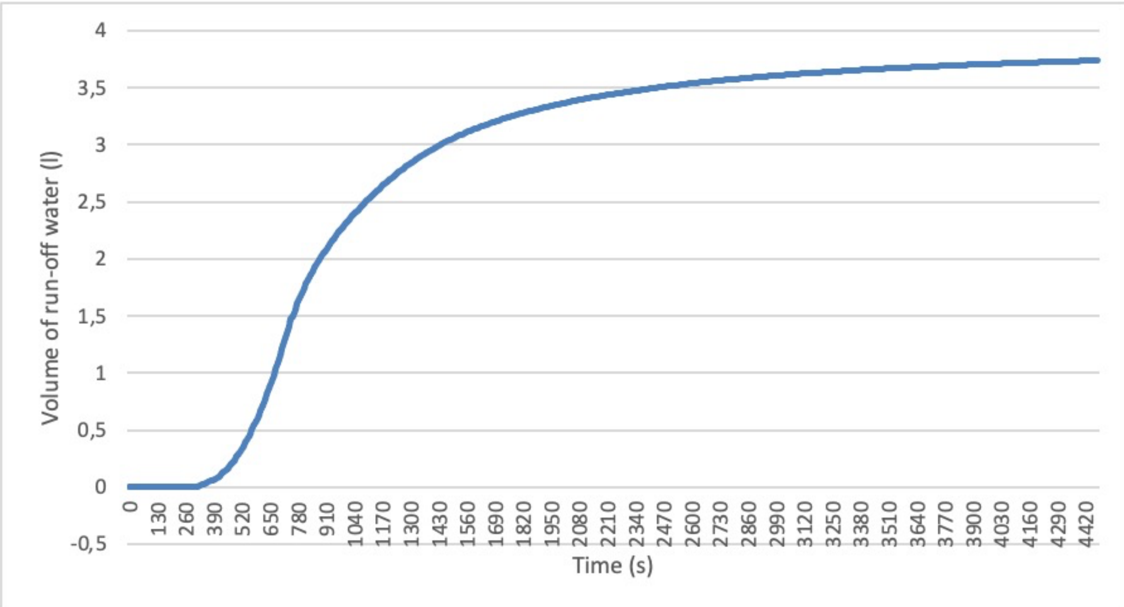

Figure 9. Water drainage on the typical green roof

5. Conclusions

Based on the performed tests, it is possible to claim that a green roof using a new type of pre-grown panels is more advantageous in terms of the time required for the construction of a green roof on a construction site. The measured data showed that the speed of the construction of this roof was 3.7 times faster than with the traditional construction of a green roof. If we combine these numbers with a real roof with an area of 100 m2 and neglect the effect of the need to machine the edges of the roof and penetrations, which will be solved in both variants by the same method, one worker can implement pre-grown panels in 5 hours and 43 minutes. In this case, the panels would already be completely green. In the case of a traditional large roof, this roof would take one worker 21 hours and 11 minutes without installing a stonecrop roofing. In the case of construction with the help of cuttings we can talk about an additional time of up to 7 hours, and in the case of spreading the carpet stonecrops approximately 2 to 4 hours, depending on the articulation of the floor plan and the number of penetrations through the roof cladding. It is, therefore, possible to see that there are time savings of more than 2 working days and the roof can be fully greened in one day. Depending on the time, there will also be financial savings corresponding to the work on the roof and the mechanization needed to transport the material to the roof, which would otherwise take 3 working days.

Unfortunately, as a green roof made of pre-grown panels gains on the structure, it then loses its ability to retain water during heavy rain, when the total water retained during the first 15 minutes of rain is approximately three times that of a conventional extensive green roof. However, there is still a great slowdown in the outflow of precipitation compared to water, which rains on the roof without any treatment, with a green roof, gravel, or the substrate itself without a hydro accumulation liner. We can therefore state that a roof produced in this way has sufficient efficiency to slow down the outflow of rainwater into the sewer. Here, however, it should be noted that the roof panels were designed from ecological and economical materials that decompose and further nourish the plants over several years in the underlying layer itself. At the same time, this degradation of the parts that separate the individual panels will lead to the interconnection of the individual panels into a continuous layer of substrate. During this time, the drainage curve should be gradually flattened and ideally at the end of the cycle, when the panels are fully interconnected, no significant difference should be seen between the curve of a conventional large roof structure and a prefabricated panel structure. However, this statement requires a further examination of the behavior of both types of roofs and careful monitoring of the degradation of individual panels and the possible side effects that this connection could cause.

There is not much fault in the construction of the roof itself from pre-grown panels or the panels themselves. It is possible to discuss their further development and the replacement of, for example, batten structures with smaller plastics or metal parts, which would increase the volume of the substrate on the roof and thus increase the retention capacity. However, the aim of this research is to create a fully ecological panel that degrades over time to form a continuous area of greenery without being disturbed by lines of plastic or metal edges, and this goal would not be easy to achieve using these materials. We can also increase the retention capacity, for example by changing the hydro accumulation material or the substrate itself or in other ways, as the ever-evolving development of pre-grown elements will be further addressed in the future.

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References

[1] Information on https://climate.nasa.gov/ [cit. 2020-08-26].
[2] Information on http://portal.chmi.cz/ [cit. 2020-08-26].
[3] Korol, E. A N. Shushunova. *Benefits of A Modular Green Roof Technology* [online]. 2016, 2016, 2016 (WMCAUS2016), 7 [cit. 2019-09-05]. Available: https://www.sciencedirect.com/science/article/pii/S1877705816329022
[4] Williams K J H, Lee K E, Sargent L, Johnson K A, Rayner J, Farrell C, Miller R E, Williams N S G, *Appraising the psychological benefits of green roofs for city residents and workers. Urban Forestry and Urban Greening 2019*
[5] Heat Island effect. *United States Environmental Protection Agency* [online]. Environmental Protection Agency 1200 Pennsylvania Avenue, N.W. Washington, DC 20460: Environmental Protection Agency, 2019 [cit. 2019-09-05]. Available: https://www.epa.gov/heat-islands
[6] Svaz zakládání a údržby zeleně. *Svaz zakládání a údržby zeleně* [online]. Brno: Svaz zakládání a údržby zeleně, 2014 [cit. 2017-11-30]. Available: http://www.szuz.cz/cs/
[7] *Standardy pro navrhování, provádění a údržbu: Vegetačních Souvrství Zelených Střech*. Brno: Odborná sekce Zelené střechy při Svazu zakládání a údržby zeleně, 2016.
[8] Hejl, M.; Mohapl, M.; Bříza, L. Modular Green Roofs and their Usage in the World. International Journal of Engineering Research in Africa, 2020, vol. 47, no. 1, p. 103-108. ISSN: 1663-3571.