Bulgarian Journal of Agricultural Science, 25 (No 6) 2019, 1083–1091

New solution – innovative design with inventive step of a super tall green building made of bamboo: "Superskyscraper in Singapore"

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Abstract

Aleksandrov, Y. (2019). New solution – innovative design with inventive step of a super tall green building made of bamboo: "Superskyscraper in Singapore". *Bulgarian Journal of Agricultural Science, 25* (6), 1083–1091

Here is reviewed an innovative solution with inventive step of the authors, concerning a super tall building, made of bamboo which is a finalist of the "Superskyscrapers – Singapore" competition – project № 1000001023 (Aleksandrov et al., 2014b)

The innovation design with inventive step of super tall buildings should be regarded as unity of heterogeneous characteristics – compositional, constructional, technological, ecological, energy, etc.

Compositional characteristics

There are three spherical solids, composed of 2, 3 and 5 volumes respectively (Fibonacci sequence).

Constructional characteristics

The requirement to use bamboo as main construction material has been a prerequisite for the decision on the external design and the geometrical shape as well as the interior of the super tall building. An innovative technical solution for the beams and columns made of bamboo is applied. The kernel of the building is made with the help of a "remaining" bamboo shuttering. The floor constructions are also made of bamboo. Elements for damping of vibrations, occurring in case of earthquakes can also be easily integrated into the construction.

Energy characteristics

Contemporary technologies are implemented in order to optimize the production of energy. Wind turbines are suspended on bent 8-shaped carrying elements, resembling the section of bamboo rods. Also, water turbines, set in motion by rainwater, collected in floor tanks are integrated in the design. Soft wastewater is collected in other floor tanks, whereas a serpentine carries the wastewater in order to warm up and irrigate the root system of the plants in the gardens and green areas present on every floor.

Ecological characteristics (a green system)

Gardens and green spaces are harmonically integrated on every floor.

Keywords: innovation design; inventive step; super tall building; bamboo, patents

Introduction

The creation of innovative solutions with inventive step leads to original architectural solutions not only in terms of elements and architectural constructions but also in terms of entire buildings. An example for this are the authors' projects presented in various competitions, i.e. Evolo in 2014 and Superskyscrapers in 2012, 2013, 2014 and (Aleksandrov et al., 2015).

In this paper is reviewed one of these projects and namely the project for a high-rise made of bamboo, designed according to the requirements of the Superskyscrapers 2014 Singapore Bamboo Skyscraper competition (Figures 1-11).

In the dissertation of the author are reviewed innovative solutions with inventive step, which focus on the chambers, intended for storage of fruits and vegetables, situated in autonomous buildings of the warehouse type.

The combination of innovation design of buildings without inventive step and the innovation design of constructions and details with inventive step, which are an inseparable part of these buildings allows to achieve a high level of competitiveness of numerous design solutions.

The main characteristics of fruit storehouses are reviewed in detail in "Chapter 2.2.1. Storehouses for fruits and vegetables, vegetable depots, vegetational structures, etc. in the monograph "Constructional and technological structures for the nutritional industry" (Vlasarev, 2014, p. 67), whereas these characteristics are also applicable in the design of fruit storehouse for skyscrapers.

In an innovative arcology skyscraper in Hong Kong, the cultivation of soft fruits and vegetables is realized in horseshoe-like hollow spaces, which are supported by the kernels of a twisted triangular prism, the latter representing the main high body of the skyscraper. The chambers for storing fruits and vegetables can be situated on specially built floors, which are equipped with refrigeration installations, meeting the special requirements for humidity, temperature, gas medium, etc. (Steel city – Container Skyscrapers, Mumbai, 2015).

In the case of single volumes with transparent covering is achieved a hothouse effect, combined with a solar system for water heating which uses rainwater, stored in special water tanks (Aleksandrova, 2011). These volumes are intended for exploitation in extreme situations (Aleksandrova, 2009). Various examples for buildings made of containers exist, whereas the containers are situated side-by-side or over each other (Woods, 2015). A prominent example for a high-rise building made of containers has been built in Mumbai (Ganti, 2015); (Steel city – Container Skyscrapers, Mumbai, 2015). Another building made entirely of containers is developed by NBRS (Duffin, 2015). However, in all mentioned solutions there are no chambers of the "container" type, specifically designed for cultivation and storage of fruits and vegetables in autonomous refrigeration environment. The energy self-sufficiency of these container buildings requires the use of passive and active systems for solar heating as well as the integration of new materials. The proportions of the used materials (Ching, 2014) are of high importance for contemporary technologies in the area of energy effectiveness.

Description of the Design

Three skyscrapers are situated on the plan. They are composed of 2, 3 and 5 bodies respectively (Fibonacci number) (Figure 1).

Fig. 1. General view (Aleksandrov et al., 2014b)

They are interconnected on every installation floor through transport pathways, which allow for the easier redistribution of the transport flow of people, e.g. in case of fire. Thus, they can be used as an additional evacuation route. In the lowest part, situated outside of the Bamboo Skyscraper are placed garages for the inhabitants – permanent inhabitants, hotel guests, office workers or facility management staff. On the garage roofs are situated gardens, as a logical continuation of the park vegetation, making part of the nearby environment. Next to the entrance of the skyscraper on several levels are situated commercial areas, cinemas, theaters, libraries, etc. These levels also include green and water areas.

Collection of waste

Soft waste is recycled below the garage level. From there, after recycling, it serves as a fertilizer for the inner gardens and green areas. Hard waste is separately collected in containers and is afterwards transported to special depots for its storage and recycling, according to material type.

Functional solution

There are elevators, situated in the central kernel, allowing for the access to all five spherical modules. According to the floor level, there are apartments for permanent inhabitation, as well as offices. The hotel part can be situated in all spheres. Every apartment has its own garden for growing own fruits and vegetables. The most common type of housing is the three-story maisonette with a fruit garden on the third floor and two vegetable gardens on the first and second floors (Figure 2).

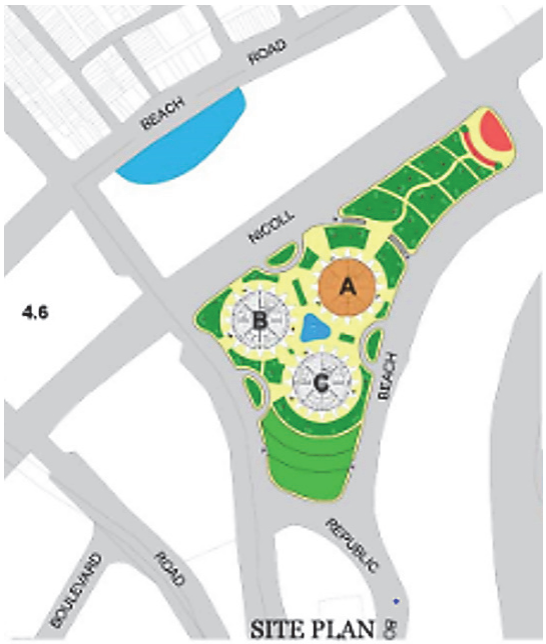

Fig. 2. Site plan (Aleksandrov et al., 2014b)
***A* – first body; *B* – second body; *C* – third body**

These gardens could be accessed not only via the internal staircase but also via the external staircase, connecting all three floors of the apartment. These three-story maisonettes can be combined with one- or two-story housing, according to the needs of the inhabitants. The root system of the plants in the gardens is also irrigated by using the method of drip irrigation with rainwater, collected in special water tanks, situated in the central kernel. In the double floor of each level is installed a tube network, reaching the root system of all plants. As well, the root system is heated by another tube network, transporting a heat carrier, taking away the heat from the wastewater, collected in separate tanks on the respective level of the skyscraper. When the root system is appropriately heated, the plants grow faster (Figures 3, 4, 5 and 6).

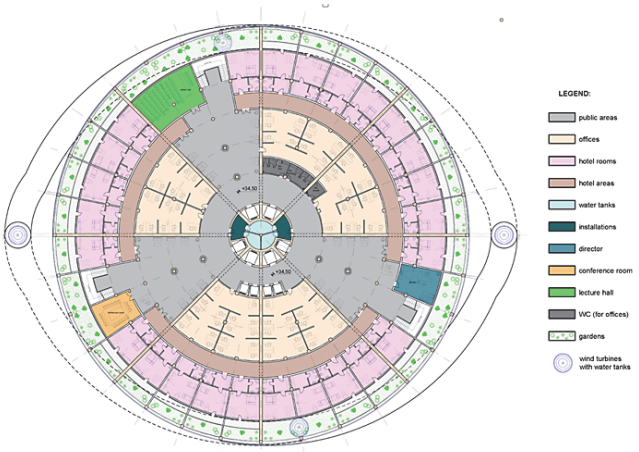

Fig. 3. Architectural typical floor plan (Aleksandrov et al., 2014b)
All rooms are equipped with their own gardens for soft fruits and vegetables

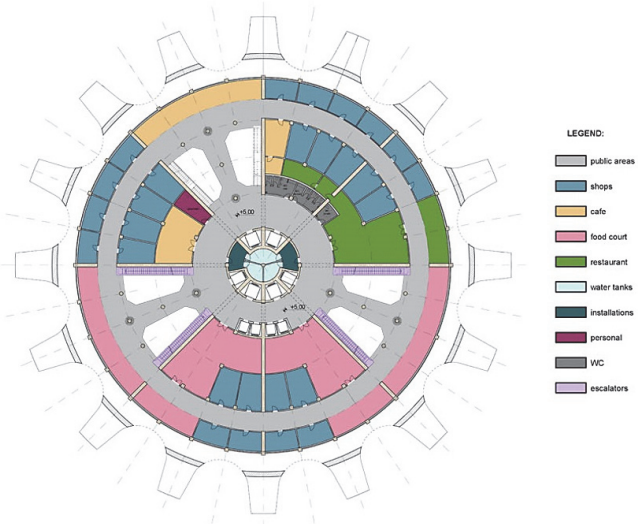

Fig. 4. Architectural plan of the second floor (level 34.50 m) (Aleksandrov et al., 2014b)
The shops are equipped with containers for fruits and vegetables

Constructional solution

The prevailing building material used in the skyscraper is bamboo. It is used for the construction of: – columns and beams; – double floor; – lattice, situated on the installation floors, reinforced where necessary by metal rods; – façade mesh; – formwork, required for the modeling of the central kernel and the carrying walls; – floor construction, reinforced by plates made of bamboo particles, connected by a cohesive mixture; – covering of the pathways, which are connecting the three skyscrapers; – protective shell, on which the wind turbines are suspended; – furniture (Figures 7 and 8).

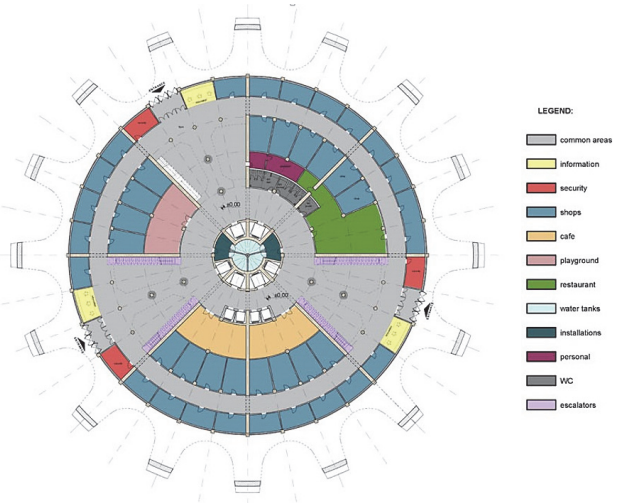

Fig. 5. Architectural plan of the ground floor (level 0.00 m) (Aleksandrov et al., 2014b)
The shops are equipped with containers for fruits and vegetables

Façade mesh made of bamboo rods

There are three variants for the bamboo façade mesh.

- First variant – with crossed bamboo rods;
- Second variant – with one-sided bamboo rods;
- Third variant – partially crossed bamboo rods, combined with one-sided bamboo rods.

There is a transparent envelope between the bamboo rods, which can be opened according to the weather conditions. The envelope is made of an innovative thin film, resistant to ultraviolet rays. With the help of this envelope, the microclimate in the premises can be controlled.

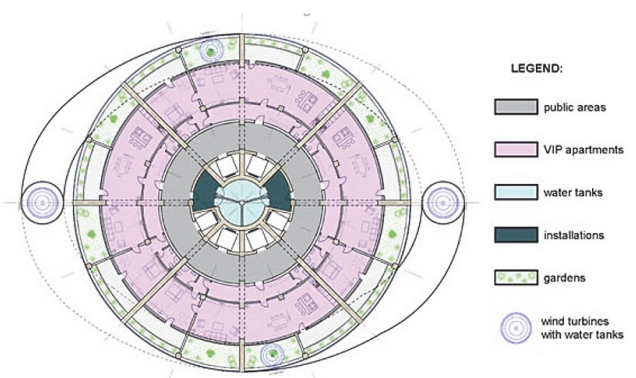

Fig. 6. Architectural floor plan – luxurious variant (level 228.50) (Aleksandrov et al., 2014b)
The VIP-class apartments are situated on an independent floor (level 228.50) and are equipped with their own gardens for fruits and vegetables

Fig. 7. Façade (Aleksandrov et al. , 2014b)

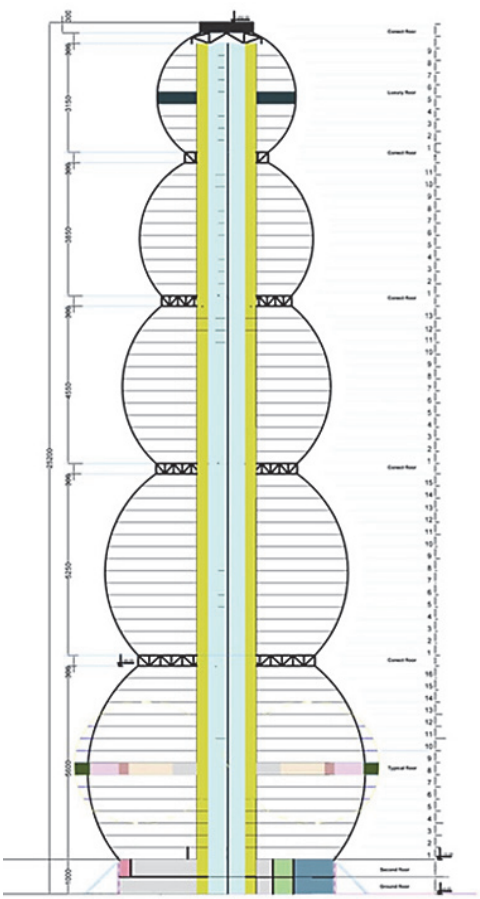

Fig. 8. Schematic section (Aleksandrov et al., 2014b)

Energy sources

Wind power

Every sphere is embraced by hoops in the form of the number eight, where the wind turbines are situated (Figures 9 and 10).

Fig. 9. Façade view with wind turbines (Aleksandrov et al., 2014b)

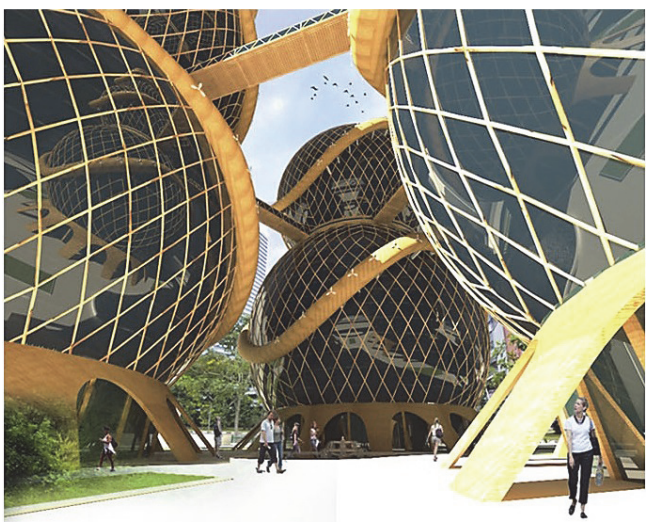

Fig. 10. Fragment of the façade (Aleksandrov et al., 2014b)

Water

The rainwater, stored in tanks in the central kernel is used to set in motion water turbines.

Extinguishing vibrations

Behind every hoop are mounted water spheres, which extinguish all types of vibrations. Each water sphere is divided into two spaces – smaller and bigger space. The bigger space is filled by rainwater, coming from water tanks, situated in the central kernel. In case of vibrations the water is being shaken and the waves throw it away through the opening, situated in the barrier wall with the smaller space. Thus, the water moves into the smaller space, which is divided into small water tubs. From there, the water squeezes via a tube network to another water tank, situated in the central kernel. Instead of water, the whole process works with small lead balls with different diameter, whereas part of the vibrations is damped through the friction between them (Figure 11).

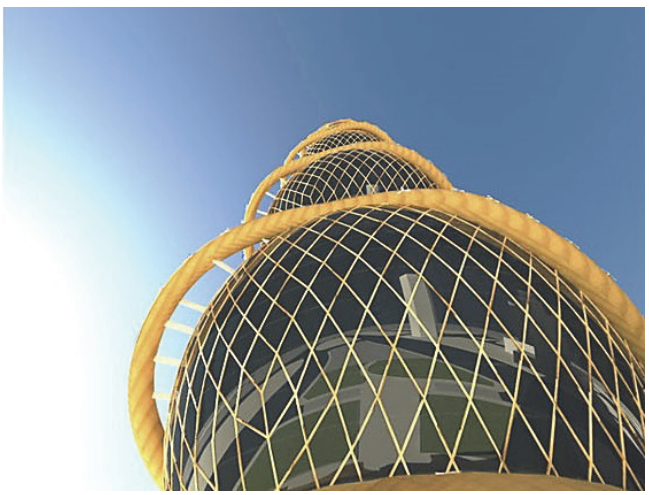

Fig. 11. View of the high body (Aleksandrov et al., 2014b)

A System for the Cultivation and Storage of Fruits and Vegetables in Containers

The issues related to the feeding of the population of Singapore can be solved by focusing on the residential areas as potential areas for cultivation and storage of produce. One solution is to use containers with two spaces – one intended for cultivation of fruits and vegetables and the second intended for their storage. The reviewed solutions are covered by patents for inventions ("Movable refrigeration chamber operating under positive temperature"; (Reg. № BG111651(A), **Patent № BG 66823);** (Aleksandrov, 2013a; 2018a), and

"System for solar heating of a refrigeration chamber operating under positive temperatures"; (Reg. № BG111658 (A); **Patent № BG 66742);** (Aleksandrov, 2013b; 2018b). In case of need, fruits and vegetables can be stored in refrigeration chambers situated on separate floors of the high-rise building (**Patent BG № 63644** "Sectional refrigeration chamber; (Aleksandrov, 2002).

Innovative solutions with inventive step to be used in the production of refrigerators for fruits and vegetables with transparent elements

The triangular panels 5 situated on the walls and the ceilings are transparent; the connections are gas-impermeable. The chambers and the containers with transparent walls and ceilings are situated over a base of channels, formed under them, whereas this base is situated directly on a rotating ring. The channels allow the air conditioning of the bottom of the chambers and the containers, in the case when they are used for refrigeration of fruits and vegetables **(**BG63644 (B1); (Aleksandrov, 2002).

Built-up refrigeration chamber. BG63644 (B1).

The chamber is used in the construction of industrial refrigerators, as well as in building of removable refrigeration tunnels. It achieves greater stability of the built-in volume. The four walls (1) of the chamber (2) are formed by beamed-walls (3) which have double T-section with trapeze-shaped belts. Panels (5), forming the ceiling and the floor of the chamber, have triangular shapes with chamfered peaks (6), and are fitted to each beamed-wall (3), by means of horizontal pivotal connections (4), fitted at the inner angle to the upper and to the lower trapeze-like belt of the beamed-walls (3) by their base, or by a triangular panel (5), respectively. The triangular panels (5) are fixed to each other at their chamfered peaks (6) by a clamp (7), and on the fronts of the triangular panels (5) sealing strips (13) are fitted, and the joints between the panels (5) at the floor and the ceiling are covered by gas impermeable layer (8). 1 claim, 4 figures (Figures 12 and 13).

The angular two-plane elements used in the floor and the ceiling are transparent. The chambers and the containers can have one or two volumes. When they have only one volume, every first volume is used for cultivation and every second volume is used for storage of fruits and vegetables (Reg. № BG111651(A), patent **№ BG 66823);** (Aleksandrov, 2013a, 2018a).

Moveable cold storage chamber for positive temperature. Reg. № BG111651 (A); Patent № BG 66823.

The invention relates to a Cold storage chamber having a natural lighting along the edges of the chamber to create a

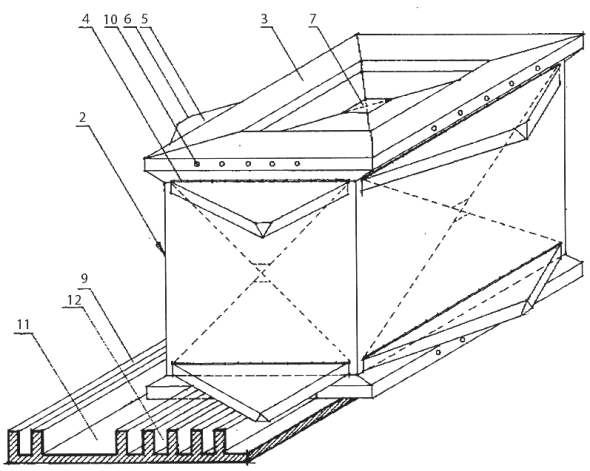

Fig.12. Refrigerator for fruits and vegetables. General view. Patent for invention "Built-up refrigeration chamber". BG63644 (B1) (Aleksandrov, 2002)

Four walls; (*2*) chamber; (*3*) beamed walls; (*4*) horizontal pivotal connections; (*5*) triangular panels; (*6*) chamfered peaks; (*7*) clamp; (*8*) gas impermeable layer; (*9*) rib; (*10*) cylindrical channels; (*11*) channel for foundation of the beamed walls; (*12*) channel

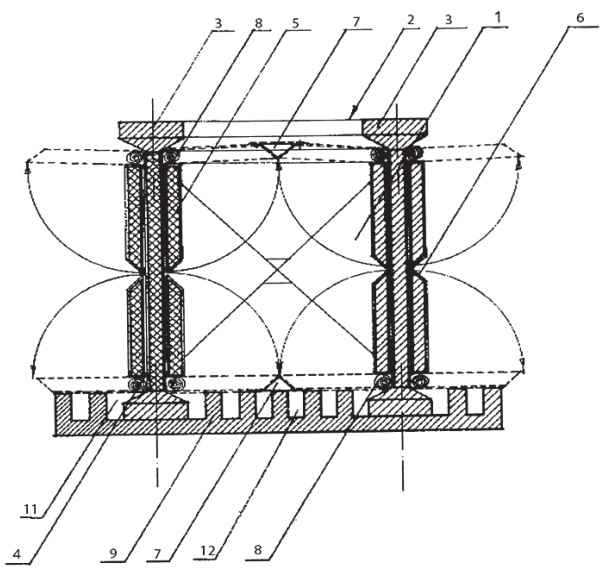

Fig. 13. Refrigerator for fruits and vegetables. Section Patent for invention „Built-up refrigeration chamber". BG63644 (B1) (Aleksandrov, 2002)

(*1*) four walls; (*2*) chamber; (*3*) beamed-walls; (*4*) horizontal pivotal connections; (*5*) triangular panels; (*6*) chamfered peaks; (*7*) clamp; (*8*) gas impermeable layer; (*11*) channel for foundation of the beamed walls; (*12*) channel

greenhouse effect. There is a possibility for artificial lighting and heating of the storage by converting solar energy into electricity through photovoltaic coatings. The cold storage chamber has a supporting structure of longitudinal transparent frames (12) and transverse transparent frames (12-a), as to the columns of the frames are installed inside transparent guides (11, 13) for securing the walls of the chamber. Along the edges of the chamber are situated transparent elements – three angular planar elements (1, 8) horizontal angular of two planar elements (2, 7), a T-shaped angular member (3, 6) and the vertical angular of two planar elements (4). The walls are covered by not transparent wall panels (10) secured to the inner side of the guides (11, 13) and the ceiling is made of not transparent ceiling panels (9) secured to the inner side of the transverse frames (12a). On the wall panels (10) and the ceiling panel (9) is arranged a photovoltaic coating (Figures 14 and 15).

The transparent angular elements are combined with solar water collectors situated on the roof of the refrigerator. When the chambers and the containers have two volumes, the first volume situated on the ring, near the facade is used for cultivation of soft fruits and vegetables, and the other volume situated near the core of the skyscraper is used for

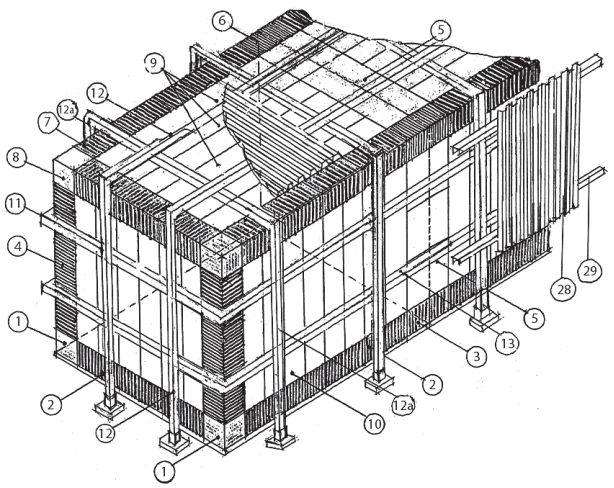

Fig. 14. Refrigerator for fruits and vegetables. General view. „Moveable cold storage chamber for positive temperatures". (Reg. № BG111651 (A); Patent № BG 66823); (Aleksandrov, 2013a; 2018a)

(*1,8*) three angular planar elements; (*2,7*) two planar elements; (*3,6*) „T"-shaped angular member; (*4*) the vertical angular of two planar elements; (*9*) not transparent ceiling panels; (10) not transparent wall panels; (*11,13*) the inner side of the guides; (*12a*) the inner side of the transverse frames; (*12-a*) transverse transparent frames; (*11,13*) inside transparent guides

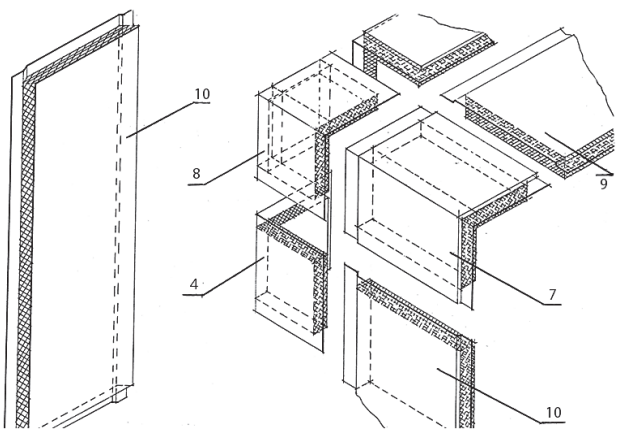

Fig. 15. Refrigerator for fruits and vegetables. The basic elements. „Moveable cold storage chamber for positive temperature". (Reg. № BG111651 (A); Patent № BG 66823); (Aleksandrov, 2013a; 2018a)

(*4*) vertical angular of two planar elements; (*7*) two planar elements; (*8*) three angular planar elements; (*9*) not transparent ceiling panels; (*10*) not transparent wall panels

their storage. The solar collectors are situated near the facade, whereas their back surface is heated by the sunrays which are reflected by the horizontal reflective surface (BG111658 (A); Patent № BG 66742); (Aleksandrov, 2013b, 2018b).

A system for solar heating of a cooling chamber with positive temperatures. Reg. № BG111658 (A); Patent № BG 66742.

The invention finds application in extreme situations and features with solar heating to achieve the positive temperature, with naturally absentmindedly solar lighting in the area of vertical joints between the panels, as well as with combined thermal insulation of walls and the roof of transparent thermal insulation, at least half-filled with energy accumulation composition. Three flat corner is filled with the external transparent layer (1-a), an inner dense layer (7), as in layers (7) shaped the first vertical zigzag channel (7-a) and the second horizontal zigzag channel (7-b), as in the channel (7-a) is a heirloom layer (6), and the zigzag shaped element (6) is fixed to the thick layer (7) with the connector (4), (7) and behind this layer (6) are located in the thin heating coils (3-b) and between the outer transparent layer (1-a) and the inner dense layer (7) is a transparent thermal insulation (2), with its transparent walls (2) are shaped confined spaces, as at least half of these spaces are filled with energy accumulation composition, and a T-shaped three-flat corner is filled with external vertical transparent layer (5), and the other two lay-

ers (1-a), and (7) are dense, such as in the layer (7) shaped the first vertical zigzag channel (7-a); and the second horizontal zigzag channel (7-b), as in the channel (7-a) is a heirloom layer (6), and Zig Zag shaped element (6) is fixed to the thick layer (7) with the connector (4)as in the sewers (7-a) and behind this layer (6) are located in the thin heating coils (3-b), and to the same layer (6) are located on the thicker heating coils (23), such as to the left of the layer (1-a) are located other vertical curved channels (7-b), and the two flat corner (on the external walls of the enclosure) is filled with outdoor transparent layer (1-a), the inner dense layer (7) as in layers (7) shaped the first vertical zigzag channel (7-a) and the second horizontal zigzag channel (7-b), as in the channel (7-a) is situated here (Figures 16 and 17).

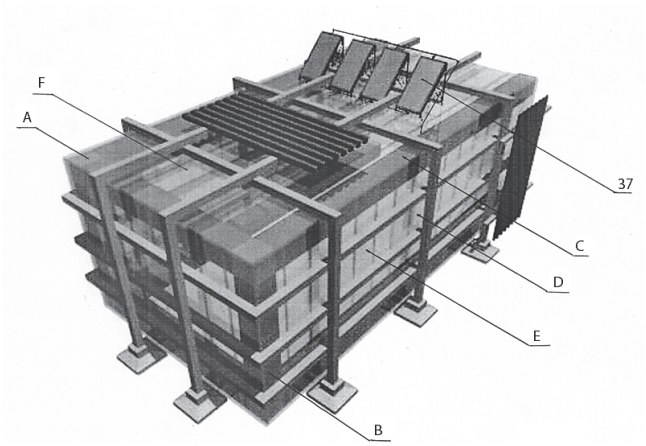

Fig. 16. Refrigerator for fruits and vegetables. Elevation. System for solar heating of cooling chamber with positive temperatures." (Reg. № BG111658 (A); Patent № BG 66742); (Aleksandrov, 2013b; 2018b)

A – three flat corners; *B* – two flat corners; *C* – „T"-shaped three flat elements; *D* – „T"-shaped two flat elements; *E* – flat vertical elements; *F* – flat horizontal elements; *37* – collectors

Functioning of the Solar System for Water Heating

Inside the hollow transparent elements 11, 12, 13 circulate a heat-carrier, set in motion by a circulation pump. Inside the internal separation wall between the two premises of the chamber, the external hollow elements are connected with outside tubular serpentines 22, 24, situated at its both sides. A second circulation pump returns the heat-carrier to the outside hollow transparent elements 11, 12, and 13. At least two circulation pumps are situated in one of the two parts of each chamber, at the beginning and at the end of the internal tubular serpentines. Thus, the heat-carrier circulates

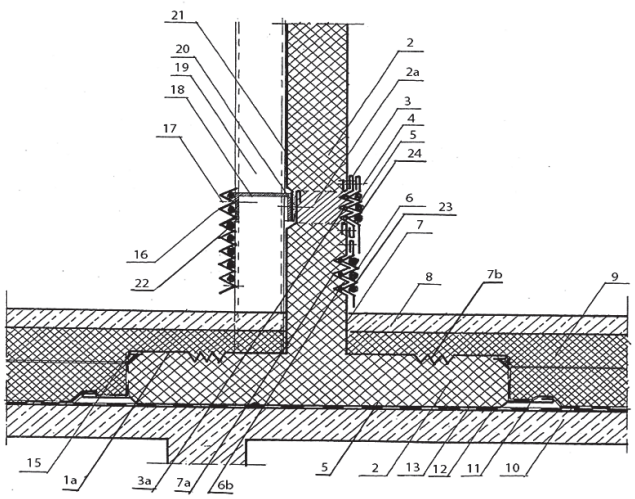

Fig. 17. Refrigerator for fruits and vegetables. „T"-shaped joint. „System for solar heating of a cooling chamber with positive temperatures". (Reg. № BG111658 (A); Patent № BG 66742); (Aleksandrov, 2013b; 2018b)

(*1-a*) external transparent layer; (*2*) transparent thermal insulation; (3-b) thin heating coils; (*4*), (*17*) connector; (*5*) "T"-shaped three-flat corner; (*6*) zig-zag shaped element; (*7*) inner dense layer; (*7-a*) first vertical zigzag channel; (*7-b*) second horizontal zigzag channel; (*21*) external vertical transparent layer; (*23*) thicker heating coils

inside the *first circulation outline***,** situated behind the transparent "cobweb" at the south façade of the skyscraper.

The *second circulation outline includes the fibers of the vertical "cobweb" structure, situated in front of the containers at the south façade of the skyscraper.* The fibers of the transparent "cobweb" represent tubes filled with heat-carrier, which form a solar water collector, connected with the help of circulation pumps with the tubular serpentines 22, 23, 24, 3-a, situated in the lower part or the separation wall between the two parts of each chamber. The heat-carrier represents purified rainwater, mixed with antifreeze liquid (if the system is to be installed in areas with low temperatures). The temperature in the two premises of each chamber is controlled by various sensors. In the container for inhabitation, which are combined with chambers for cultivation of soft fruits and vegetables, positive temperature is maintained with the help of the external hothouse effect, occurring in the south façade covering, the internal hothouse effect, occurring inside the containers and chambers themselves as well as the two circulation outlines. *A third circulation outline* for heating of the "cobweb" type can be installed as a hung ceiling in the premises for inhabitation (Figures 16 and 17).

Conclusion

A well-balanced synthesis of heterogeneous characteristics has been achieved, which has resulted in an innovative solution. The bamboo elements and details implemented in the construction are designed with inventive step, which has contributed to the originality and uniqueness of the architectural image of the building, whereas the building system, which is also made of bamboo, has highly increased the competitiveness of bamboo as a construction material on the market for super tall buildings (Figures 1-11)

In the reviewed skyscraper, the cultivation of fruits and vegetables as well as their storage is realized directly in the areas situated adjacent to the shops on the ground floor (level 0.00 m). (Figures 4 and 5). The surplus of fruits and vegetables can be stored in the container chambers, situated in the three parts of the transportation corridor on the ground floor (level 0.00 m) or the second floor (Figures 4 and 5)

The internal spaces of the skyscraper, used for cultivation of fruits and vegetables eventually become an integral part of the urban environment. There are containers situated on the roof, too. The sunrays which pass through the transparent elements situated in the walls and the ceilings maintain a positive temperature which is required for the cultivation and storage of soft fruits and vegetables (Reg. № BG111651(A); Patent № BG 66823); (Aleksandrov, 2013a; 2018a).

In case that the need for a higher temperature in the container arises, a system for solar water heating is used, whereas the solar collectors are situated on the roof (Reg. № BG111658 (A), Patent № BG 66742); (Aleksandrov, 2013b; 2018b).

References

Dissertations

Aleksandrova, L. (2009). Dissertation, Adaptation of the chambers of fruit storehouses and refrigeration warehouses for use for medical purposes in extreme situations, Sofia, 2009.

Projects of the competitions in Singapore and Mumbai

Aleksandrova, L., Aleksandrov, Y., Hasan, M. & Mustafa, M. (2014b). Superskyscrapers Bamboo Skyscraper Singapore – 2014, Finalist project № 1000001023.

Aleksandrov, Y., Aleksandrova, L. & Mihaylova, M. (2015). Mumbai 2015, Project number 1000001600, Finalist.

Books

Ching (2014). Francis Ching, Architecture: Form, Space and Order, 4th Edition, Wiley. ISBN: 978-1-118-74513-7.

Vlasarev, D. (2014). Chapter 2.2.1. Storehouses for fruits and vegetables, vegetable depots, vegetational structures, etc., p. 67, in the monograph Constructional and Technological Structures For The Nutritional Industry". 2014. ISBN: 978- 954-331-053-1.

Competition briefs

Steel city – Container Skyscrapers, Mumbai, 2015.

Patents

Aleksandrov, Y. (2013a; 2018a). Moveable cold storage chamber for positive temperature. Reg. № BG111651 (A); Patent № BG 66823.

Aleksandrov, Y. (2013b; 2018b). A system for solar heating of a cooling chamber with positive temperatures. Reg. № BG111658 (A); Patent № BG 66742.

Aleksandrov, Y. (2002). Patent BG 63644 (B1). Built-up refrigeration chamber, Classification: *E04B1/343; E04B1/74; E04H5/10,* Espacenet (Bg).

Aleksandrova, L. (2011). Patent BG66192 (B1) – 2011-12-30, Solar Energy Application for Hot Water Residential Supply and Air Heating in a Modular Medical Unit (Operation Theatre) in Extreme Situations. Classification international F24J2/42, cooperative: Y02E10/40. www.espacenet.com

Projects with containers

Duffin (2015). Andrew Duffin, the NBRS team, 2015. Shipping Containers Create Super Skyscraper in Mumbai, Sep 21, 2015. http://nbrsarchitecture.com/nbrs-projects/

Ganti (2015). Ganti + associates (ga) design 2015.Shipping container skyscrapers proposed for **Mumbai**. Design / Green Architecture. September 1, 2015.

Woods (2015). Tom Woods. 23 Shipping Container Home Owners Speak Out: "What I Wish I'd Known Before Building My Shipping Container Home". Container Home Plans. www.containerhomeplans.org/2015/04/what-i-wish-id-known-before-building-my-shipping-container-home/

Received: July, 31, 2019; *Accepted:* August, 5, 2019; *Published:* December, 31, 2019