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INNOVATIVE TALL BUILDINGS WITH SPHERICAL SHAPE

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ABSTRACT

Geometry and shape have notoriously great influence not only on the aesthetic but also on the performance and the engineering of every building. This particularly when the dimension and the volume become pretty high as well as the geometry is unconventional. Tall and huge buildings are currently based on pyramid or conic shapes, while spherical buildings are very uncommon, though they offer very interesting perspectives in terms of urban, functional, architectural and engineering solutions. An innovative and very promising design step is to consider this particular kind of tall and huge buildings, as large containers for some smaller multifunctional buildings, to be built inside their volume upon special platforms working like 'sphere' floors. Moreover one of the great advantages provided by a 'sphere' is the concentration of several buildings within a single volume, so reducing the land use as well. These topics have been recently investigated within CIS-E of Politecnico di Milano. The present paper reports on the results concerning the study performed on the functional design, the indoor distribution, the natural lightning modeling and the envelope design and maintenance, as well as the problem of their energetic planning and building services integration, with particular focus on those aimed at energy consumption reduction, maintenance and exploitation of renewable energy sources.

Keywords: sphere, innovation, tall building, innovative building, renewable sources, energy

Introduction

Tall and huge buildings are currently based on pyramid or conic shapes, while spherical buildings are very uncommon, though they offer very interesting perspectives in terms of urban, functional, architectural and engineering solutions.

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Spherical buildings have up to now been designed as multifunctional containers (e.g. the Globe Arena in Stockholm, that is one of the largest, most famous and successful spherical building ever experimented – see Fig. 1, or the Technosphere, designed by James Law Cybertecture – see Fig. 2).

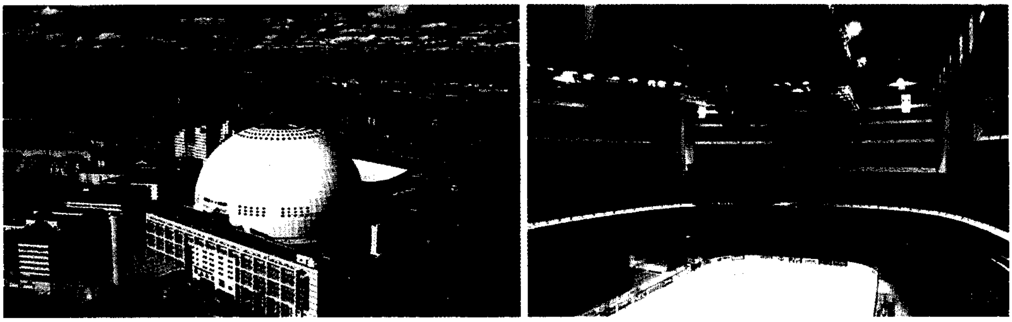

Fig. 1. Example of spherical building: Globe Arena, Stockholm, Sweden

A further, innovative and very promising design step is to consider this particular kind of tall and huge buildings, as large containers for some smaller multifunctional buildings, to be built inside their volume upon special platforms working like 'sphere' storeys. This idea (the so called 'Città Ideale'), proposed many years ago by Italian architect Guglielmo Mozzoni, has been recently investigated within CIS-E of Politecnico di Milano and the research is still in progress.

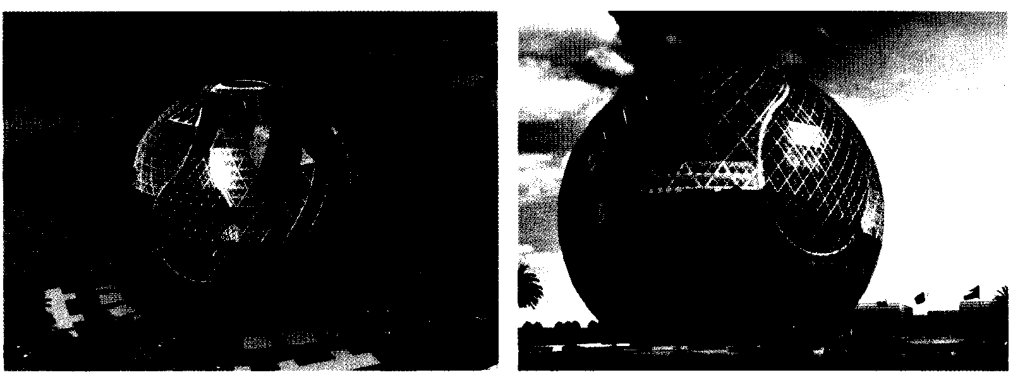

Fig. 2. Example of spherical building: the Technosphere, designed by James Law Cybertecture, is to be located in the Economic Zones World in Jabel Ali, Dubai, UAE.

The study has been referred to the case of a sphere having a 80 m radius, about 24 m inter-story height and about 19 m inter–story net height [1] [2]. At each floor the deck works as a foundation mat for the buildings to be built inside the 'sphere'. A circular hole in the floor decks (called 'oculus') is placed around the vertical axis of the sphere with the aim of providing natural light and ventilation to the inner buildings. The constructions built on the floor decks will be made of steel, wood or polymeric materials to keep their weight low together with that of the 'sphere'. The sphere, being a symmetrical building, has a better structural behavior under the dynamic loads (wind and earthquake) in comparison with other tall buildings [3] [4] having different shapes and heights [2].

The present paper reports on the research results concerning the aspects of the indoor functional distribution, the natural daylighting modelling, the facilities and building services integration, the sphere envelope design and maintenance, as well as the energy planning and design for this kind of multi-storey spherical buildings.

Functional Design

Geometry and shape have notoriously great influence not only on the aesthetics but also on the performance and the engineering of every building. This particularly when the dimension and the volume become pretty high as well as the geometry is absolutely unconventional.

As to the sustainability and energy saving aspects, the ratio between the external surface of the 'sphere' and its heated volume shows significant advantages in terms of heat flows when compared with other kind of tall buildings. Moreover, in cold climates compact forms of architecture are more frequent. In hot climates, instead, buildings characterized by more articulated shapes are preferred.

If in traditional multi-story buildings the polyhedra characterized by the lowest S/V (Surface/Volume) ratio is the cube (with S/V = 6/d, where 'd' is the cube side), considering the solid of revolution it immediately appears that they are characterised by higher compactness. Among all these, it is in particular the sphere that has the lowest S/V ratio (S/V = 3/r, where 'r' is the radius of the sphere). To maximize the compactness, the radius of the sphere should be increased, so giant structures represent one of the best solutions from the energy saving point of view. At the same time the spherical structures, in comparison with other buildings having equivalent geometric features (volume and height), have lower S/V ratio, thereby reducing the costs for the façade's construction and maintenance. Table 1 shows how the shape of a building can affect its S/V ratio, comparing five different types: spherical (80 m radius), rectangular, cylindrical, pyramidal and conical, all characterized by the same gross volume [1].

Table 1. Shape, slenderness (height/side or height/radius) and S/V ratio range.

Type of Building	Surface [m^2]	Volume [m^3]	Slenderness ratio	S/V [m^{-1}]	Δ S/V
Sphere	80,424.77	2,144,660	1	0.038	
Parallelepiped	137,201.75	2,144,660	8	0.064	+ 71%
Cylinder	130,423.12	2,144,660	16	0.061	+ 62%
Pyramid	165,127.61	2,144,660	12	0.077	+ 105%
Cone	146,268.31	2,144,660	24	0.068	+ 82%

The distribution of functional areas within the 'sphere' has been closely related to the study of the natural lighting of the indoor spaces. The analysis and the particular shape of these spaces have led to the development of many hypotheses regarding the functional design and the number and position of the vertical connectives (see Fig. 3 and Fig. 4).

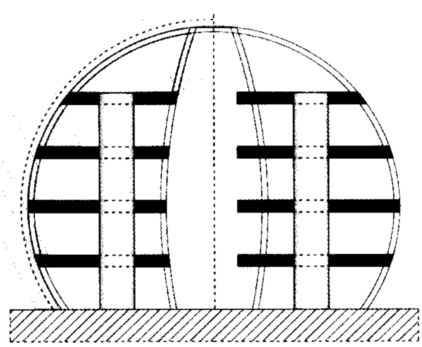

Fig. 3. Example of vertical connective position and different floor natural lighting conditions.

This in order to ensure the vertical continuity and a favorable distribution of these elements in the sphere volume. Following this layout and design strategy, buildings that need good natural lighting are placed in a more external and advantageous position. Therefore all the residential areas have been located at the upper floors, while in the lower part of the sphere, where the natural daylight is less available, commercial and service areas have been located.

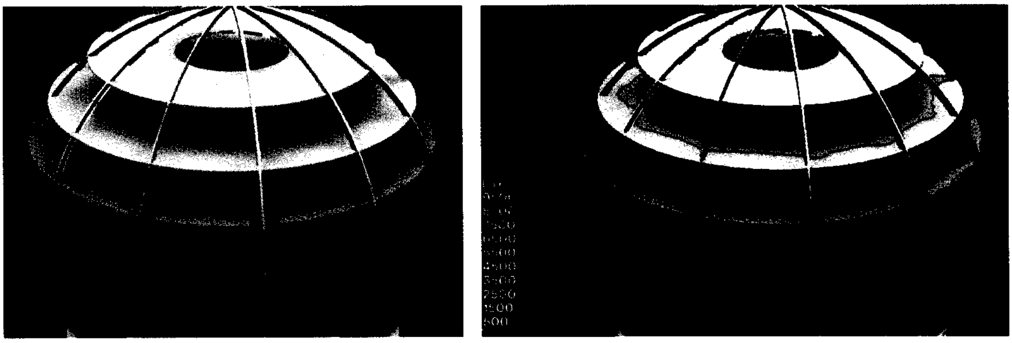

Fig. 4. Sphere general views: render of the structure and example of isolux curves at different floors.

The natural indoor lighting has been evaluated considering different types of glazing and different values of reflection coefficients of the interior finishing, in order to optimize the daylight diffusion towards the interior of the 'sphere'. This especially on the lower floors, while on the upper floors the shielding aspect has been considered too. The simulations have been performed using the software Autodesk Ecotect Analysis and Radiance (see Fig. 5 and Fig. 6).

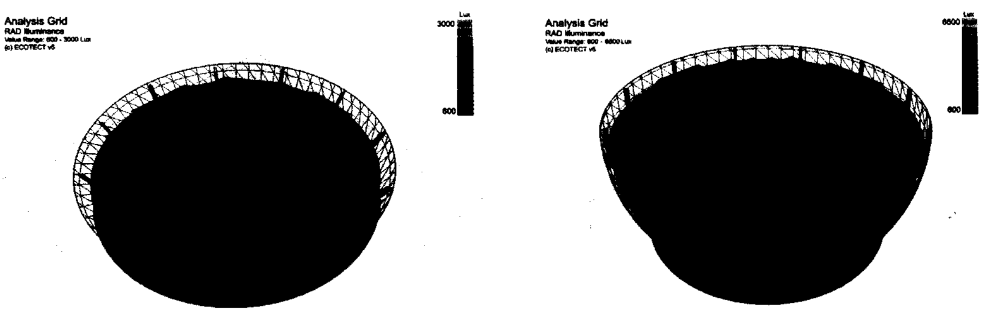

Fig. 5. Illumination analysis on lower and intermediate floors (overcast sky).

Regarding the envelope, the 'sphere' has been conceived both as an 'open' structure or as a building with its own 'skin'. The second case is more appropriate for continental climates, especially if the envelope is a high performance curtain wall (single or double skin typology), able to ensure an optimum natural lighting throughout the year, to control the thermal loads in the hot season and to minimize the heat losses in the cold one. The integration – optimization of solar shields have been considered for both the above mentioned skin types.

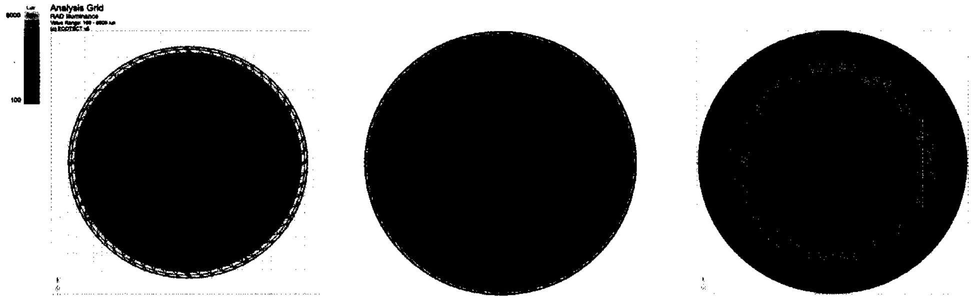

Fig. 6. Illumination analysis at different floors (overcast sky).

Among the analysed solutions, the envelope has been considered as a curved surface, to highlight the sphere concept, as well as a more articulated one, with some curve and some other instead plane parts (in the latter case the position of the vertical transparent wall can be placed closer or further away from the outer sphere surface - see Fig. 7). This allows the creation of greenhouses and/or outdoor terraces, which can be conveniently used when the outdoor climatic conditions are favourable. Different envelope solutions might also be combined in order to obtain buffer zones, resulting in a better indoor climatic control.

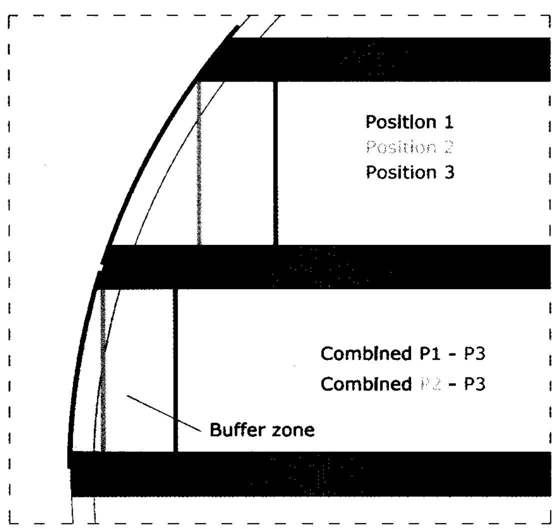

Fig. 7. Examples of envelope position and layer combinations.

As already mentioned above, the 'central core' has been designed as a volume suitable to provide the right amount of natural lighting and fresh air from the top to the bottom. To this regard, it is appropriate to equip the building envelope with opening parts, in order to guarantee, according to the outdoor conditions, favourable and effective air exchange. The possibility to switch automatically to a mechanical system with heat recovery, ensuring the necessary air exchange with reduced thermal losses in the cold season, has also been considered.

The integration of shielding and active elements in the façade (e.g. solar thermal collectors and photovoltaic panels) has implied to schedule the maintenance (ordinary and extraordinary) of these surfaces and components. This in order to keep the envelope performance, aesthetic included, and the active systems efficiency at the right level over the years [5].

Regarding the envelope maintenance (that a good construction quality can reduce but not certainly eliminate), it has been carefully considered the problem of working in safe conditions over and under the two hemispheres. The solutions defined to allow the execution of the operations to be included in the maintenance schedule (controls, cleanings, repairs, replacements, etc.) are: gantry systems (see Fig. 8), which can move along the circumference on rails integrated in the building envelope, and a special system of fix hidden guides, fasteners, hooks and removable ropes to allow specialized climbers to carry out the maintenance operations. In this case no specific internal spaces or structures of particular importance are required. Moreover there is no need of a structural reinforcing of the building to support additional loads and the aesthetic of the building is preserved, because no permanent and visible accessory structures are needed [5].

Fig. 8. Example of traveling gantry system for the envelope maintenance.

Building Services Integration and Design

One of the great advantages provided by a 'sphere' is the concentration of several buildings within a single volume, so reducing the land use. Another great advantage is the lower energy demand given by its shape, which can result, in particular, in the reduction in the total amount of surface needed for solar, thermal and photovoltaic, gain systems installation to be considered to meet the pivotal 'Zero Energy Building' goal [6]. Furthermore, the higher energy efficiency and the integration in the building envelope of active systems could lead, in perspective, even to spherical buildings producing more energy than they consume. This even if a 'sphere', compared to buildings with traditional shape, has a lower surface that can be used for the installation and integration of systems for the exploitation of renewable energy sources. If usually the goal of 'Zero Energy Building' calls for an integrated building and systems design, aiming at lowering the extent of the energy systems using renewable sources, the 'sphere' could be considered more like a 'nearly zero energy district' than a 'nearly zero energy building'. This results in the possibility of renewable energy sources exploitation also with today urban and/or district scale technologies (e.g. wind, biomass or biogas powered district heating, seasonal thermal storage, etc.), usually not adoptable when dealing at a traditional building scale [6].

In the research herein presented, the 'sphere' design hypothesis has been to maintain a temperature inside its volume ranging from 15°C in winter up to 28°C in summer, while within the buildings to be built upon the 'sphere' decks temperature and humidity conditions are set and maintained on the levels required by their specific use.

As to the system distribution, the considerable size of the 'sphere' has led first of all to the choice of locating the main technological stations in the basement, while services substations have been displayed at each main floor. The particular building shape has led to a vertical plant distribution that is barycentric to the decks circular crown (see Fig. 9). In particular, cavities and technological substations have been placed close to the vertical connectives, creating volumes that are real 'services blocks'.

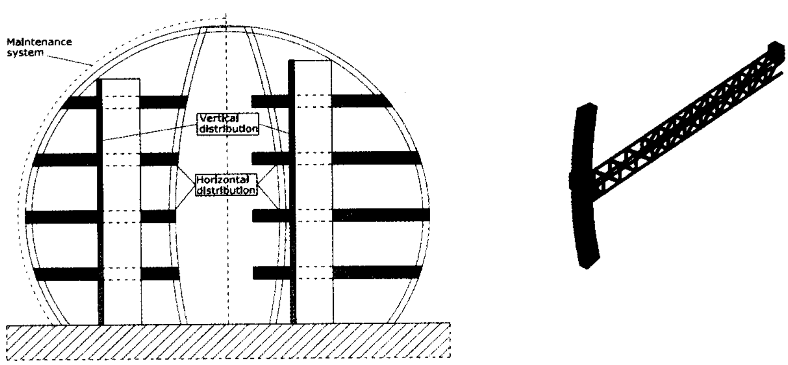

Fig. 9. Example of vertical and horizontal building services distribution (left) and example of a radial truss (right) where building services can be integrated.

The horizontal plant distribution is integrated within the slab's structural solution, both above, below and through the bearing parts. Regarding the distribution above the slabs, floating floor solutions for the horizontal paths have been considered. Some solutions based on renewable sources have been studied: a geothermic system for the air-conditioning needs, a solar thermal panels system to produce the hot sanitary water and a photovoltaic plant for the electric energy production, integrated in the building shielding systems, when and where it is adopted.

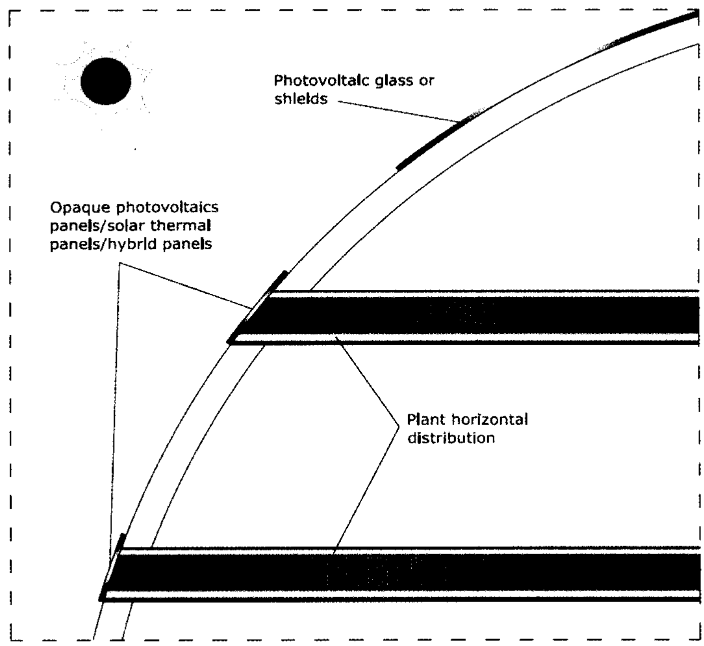

Fig. 10. Hypothesized position of photovoltaic modules.

In particular, the upper part of the sphere, characterized by favourable exposure, has been considered for the integration of active solar and wind systems. In this case, semi-transparent photovoltaic glasses (see Fig. 10 and Fig.11) can provide an estimated electric peak power of about 550 kW. The use of photovoltaic systems also in parallels (balustrades) and meridians finishing elements (see Fig. 10) turned out to be of good advantage.

Fig. 11. Example of transparent photovoltaic panels.

In the lower portion of the 'sphere', solutions taking advantages from geothermal energy can be properly integrated, starting from the foundation structures. Different ground-cooling technologies are available and they can be applied to very different building and in various climates. Since ground cooling utilizes environmental energy, an accurate analysis of the microclimatic condition and the soil around the building is necessary in order to estimate the ground-cooling potential and to decide which technique should be applied to the building.

For instance, it has been evaluated that the heat and cooling energy gain by Earth-Air Heat exchanger (EAHX) might meet the actual energy demand of the building ventilation system. In case the heating or cooling energy gain should be lower than the corresponding energy consumption, the supply air should be heated or cooled. Considering the 'sphere', a preliminary assessment of the efficiency of a EAHX system, using thermal simulation software of a geothermal system (GAEA, which allows the calculation of the heat flux exchanged between air and ground), has been performed. With soil and climate characteristics typical of northern Italy, this system should reduce cooling and heating loads by about 46% within a year [1]. At the same time other strategies can be conveniently pursued: for instance the remaining heating load can be generated by an absorption heat pump complemented by a system of thermodynamic solar concentration so that they can produce electricity and heat for domestic use at the same time.

Finally, a system of pneumatic solid waste collection has been chosen. This system, made up of charging stations, pipes, and containers for the collection, is able to transport and collect waste and it is completely automated. It is equipped with a network of horizontal and vertical pipes, where wastes are collected thanks to a pneumatic transport system, connected to the waste collection station. The drop-off points have been located both in public spaces (close to the vertical connectives) and in the common areas of the buildings, while the horizontal pipes are completely integrated in the overall slab thickness.

Conclusions

The paper reports on the results of the research, still in progress, performed on the functional design, the inside distribution, the envelope design and maintenance of high multi-storey 'spheres', as well as the problem of their energetic planning and building services integration. It examines and shows some of the most significant functional design solutions developed, with particular focus on those aimed at energy consumption reduction, maintenance and exploitation of renewable energy sources. In particular, it is noted that:

- high multi-storey 'spheres', when considered as large containers for some smaller multifunctional buildings, can be an innovative and very promising design challenge;
- the spherical structures, in comparison with other buildings having equivalent geometric features (volume and height), have lower S/V ratio, thereby reducing the costs for the façades construction and maintenance, as well as the land use;
- the distribution of functional areas within the 'sphere' has been closely related to the daylight study of the indoor spaces;
- the 'sphere' has been conceived both as an 'open' structure or as a building with its own 'skin', this second more appropriate for continental climates;
- the 'central core' has been designed as a volume suitable to provide the right amount of natural lighting and fresh air from the top to the bottom of the 'sphere';
- the building shape has led to a vertical plant distribution that is barycentric to the decks circular crown;
- renewable energy sources systems have been integrated: a geothermic system for the air-conditioning needs, a solar thermal panels system to produce the hot sanitary water and a photovoltaic plant for the electric energy production.

The paper highlights this innovative and very promising design step of the still in progress research, that considers this particular kind of tall and huge buildings as large containers for some smaller multifunctional buildings, to be built inside their volume upon special platforms working like 'sphere' floors.

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