8. Self-built Geodesic Geometries

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Abstract In the second half of the last century self build homes based on geodesic geometries building systems became popular among alternatives communities for house building. However in the present those technologies are used almost exclusively in hightech solutions for large-scale and elevated budgets infrastructure.

The precedents of implementation of these technologies in lowtech environments and in self build are not positive. Deficiencies in the available information, as well as misunderstandings and conceptual barriers that prevent their proper development persist today and these technologies have been relegated to a third plane. The technological and access to information and technology panorama has radically changed during the last 50 years.

This research shows geodetic systems, their properties, characteristics and case of studies, the consideration of sustainable due to the adaptability to local materials along with the speed of empowerment and assembly, not only to the environment but also to the communities, bringing them development and resilience.

Key words Geodesic Structures; Empowerment; Sustainable; Lowtech; Self-build.

1 Introduction

In the first half of the twentieth century Walther Bauersfeld and Richard Buckminster Fuller presented to the world the geodesic technology for the construction of domes. This was popularized in the alternative communities of the '60s, becoming the symbol of the freedom to self-build one's own shelter. At the present time the geodesic systems are used almost exclusively in hightech
solutions for large-scale and high-budget infrastructure as sport pavilions, airports, etc.

However several experiences have demonstrated that a low-tech version of these technologies can provide added and without competition values for their applications in other contexts. The resources use efficiency, the installation speed and simplicity, the modularity of the construction, the preproduction, transport, evolution and consolidation of the generated structures possibilities make geodesic structures very appropriate for the self-build homes and community spaces in devastated by natural or anthropic phenomena areas (Serrano Rodriguez 2011), or in other places where the socio-economic circumstances may require it. The adaptability to the local materials along with the speed of empowerment and assembly make the geodesic system, sustainable systems not only towards the environment but also toward the communities bringing them development, resilience and not the dependency that often accompanies aid actions.

2 State of the art

The '60s and '70s self-build experiences took place in precarious situations, without the organization and the necessary knowledge, built by the momentum of enthusiasm for the space race and in the midst of social revolutions that raised these systems to a symbol of freedom.

As Kenner relates until 1966 some figures from 'Popular Science Monthly' magazine were all anyone outside the circle of Fuller licensee had to go on (Kenner 1976). That is due to the fact that the development of these constructive systems was connected, at the beginning of the last century, with military uses and technologies. The knowledge was held as a state secret, and for its handling the utmost discretion was required, with the aim of preventing the passage to the enemy.

It wasn't until 1970 when the factor charts with the necessary data for construction, the chord factors, were put at disposal of the general public thanks to the publication of "Domebook 1" (Kahn 1970), becoming reference and boosting a wave of geodesic constructions based on its majority on the icosahedron. This publication as well as the following (Kahn 1971), (Prenis 1973), (Yarnall 1978) was lacking in of scientific character in its theoretical description of the technology, and was made up of inaccurate stories about the developed of several constructive experiences. The data and some of the basic concepts contained in them did not coincide despite being generated, in theory, with the same methodologies. That helped to create the confusions, doubts, difficulties and pathologies which have be attributed to the system.

Today the Internet gives us the possibility of gaining a huge amount of material and documentation. However it's very difficult and virtually impossible for those
who are approach for the first time to this argument, to decipher the information of the theories that are promulgated and repeated without basis or critical analysis.

The difficulties in the approach to the geodesic design owe historically also to the complexity of the spherical design that is governed by rules and has an unique vocabulary; intuitive elements that we possess for the design on flat surfaces can't be applied. That intervenes especially in the subdivision of the spherical surface for the creation of a geodesic mesh, as indicated by Popko "It is easy to evenly divide the circumference of a circle on a computer to any practical level of precision. It's not so easy to evenly subdivide a spheres, computer or not" (Popko 2012).

The experiences that we have developed have shown us that, as well as for the correct use of a mobile phone advanced knowledge of computer science or electronic engineering are not necessary, for the right self-build and consolidation of geodesic structures are not needed furthered studies on spherical trigonometry, stereographic projection or coordinates systems rotation methods. Today those knowledges are no longer essential to work on geodesic designs. On the basis of the existing charts, those can be adapted to the chosen constructive system and to the material using a very small number of theorems of euclidean geometry, and neither can this would be necessary with already adapted proposals that could be scaled lineally with a simple domestic calculator and adapt to the needs of each one. At the moment adapted, reliable and consistent proposals accompanied by simple enough for their use instructions, have not been distributed. The real problem does not lie in the subdivision methods, which have been deeply studied, but in the adaptation of the results to the different building systems that can be used for the construction. So far geodesic domes have been considered as a single and constructive system.

It's essential to avoid this consideration, to begin studying and to defining the characteristics of each constructive system and set up appropriate geometries and practice for their implementation. We consider the lack of adaptation to the different building systems as the main barrier for the system effective use. That's why more than a technical development the priority would be to change the approach and to get closer to the argument in a critical and scientific way that could provide answers to the questions that have generated the research that we are presenting. We are convinced that the only this way the technologies used for the construction of geodesic structure could be adapted effectively for their use for self-build in lowtech environments.

Our research has listed more than a dozen of building systems, divided into three technological families according to the orientation of the assembly systems of the constructive elements that compose the structure. Every family comprises diverse building systems, each with its own technology needs and specific characteristics.

1 “Geometric Independent Union”, “Radial Union” and “Tangential Union”. (Stasi et al. 2016)
The constructive experiences of prototypes and real projects developed starting from these assumptions have shown that it's possible to implement structures with untrained workers and with very simple training and assembly systems.

The proposals developed by our research focus on technological accessibility to the building of structures of maximum diameter of 12 meters, with particular focus on the between 9 and 6 meters, which although are limited dimensions are not unimportant as they generate 113, 63 and 28 square meters open spaces respectively. These measures allow us to keep us in our requirements of infrastructures and lowtech technologies and are suitable to generate homes and community spaces in self-build in a sustainable way.

Our vocation is to work with wood as starting material, specifically with the one that comes from the pallets that arrive with the humanitarian assistance in those area hit by disasters, developing in parallel different studies and constructive experiences starting from other materials. The construction should be carried out by a small group of unformed workers, directed and coordinated by a single person with a basic training that could be possible to receive in just one day, and that would be possible to provide even at distance. It should not include the use of cranes or other large-scale infrastructure. Our research has been conducted to show that approaching this field of study with a new focus it's possible to create accessibility protocols for this technology, capable of promoting its application under lowtech and self-build schemes and without the need for prior knowledges. Experiences developed from our hypothesis have confirmed it, shown that thanks to these protocols is possible even to self-build structures that in principle seem to present great complexity.

3 Case studies

Staring 2010 a work over this systems and their sustainability has been developed and phases of research, teaching and implementation of its results in up to 20 real cases, being those projects, workshop or prototypes, have been alternated. Every experience has been articulated in the broader scope of the investigation as a whole and has served to make progress in the various aspects that compose it. It has been essential to be able to check in real situations the intuitions developed during the investigation and to be able to move forward in the theoretical development of the systems, basing on the experience gained during the construction, completing this cycle with the teaching and participatory activities to adapt them to the empowerment of communities.

The first experiences were developed collaborating in the assembly of different light geodesic structure based on tubular elements in event and fairs between 2007
and 2008. Those were fundamental for the rapprochement to the geodesic geometries and to the factors to be taken into account for their construction.

Between October and November 2010 the first two geodesic structures were designed and built. One of them for the central roof of the ElNodo Cultural Center, made in Mexico with the "Geometric Independent Union" constructive system, providing the opportunity to face the construction and the consolidation of a permanent, complete and closed large scale structure. Despite of the success of our proposal to adapt to self-building schemes, the chosen constructive system demonstrated shortcomings in its adaptability to the lowtech environments, as it had to resort auxiliary medias of limited accessibility, as a crane or to the work of specialized welders. The experience of the construction from beginning to the end of a structure of such magnitude has been, without a doubt, a major milestone for the development of the successive experiences.

3.1 Wood models - Tangential Union, Brujodesic

Between 2012 and 2013 the first wood prototypes in with lowtech approach and designed specifically for the self-building were constructed. The aim was to find an easy implementation system, that with simple and repetitive operations could be built with basic tools and that could assume the measures difference between the pallets tables that was intended to use. As references of a system capable to adapt to the established requirements couldn't be found was conceived and designed the Brujodesic system a new constructive system for the construction of wooden geodesic structures that, in addition, reeling purely on flat cuts places itself transversally in the technological landscape being realizable with hand tools as well as with CNC milling machines, passing through mitresaws or other power tools.

Animated by the possibility of a specific order in July 2012 the first prototype which served to get familiar with the construction of this constructive system in concrete was built and it served at the same time to convince the client about the project. Three months later the construction of La Casa di Marcello started.

2 Saltillo, Coahuila de Zaragoza. Design and construction by Ctrl+Z (Gianluca Stasi) and Straddle3 Constructors s.l. Construction in collaboration with A.C.elNodo. Geodesic portion, Ø26, 5m. Steel structure.
3 System conceived and designed by Ctrl+Z (Gianluca Stasi).
4 Girona. Spain. Design Ctrl+Z, Construction Ctrl+Z (Gianluca Stasi) and NoSoloPaja. Geodesic Dome v4, Ø 2,0 m. Pallets wood structure.
5 Girona. Spain. Design Ctrl+Z. Construction Ctrl+Z (Gianluca Stasi) and NoSoloPaja. Geodesic Dome v3, Ø 6,0 m. Pallets wood structure.
The structure was carried out in a week with friends and volunteers help. The workforce alternation and the different training prompted the creation of the firsts technology accessibility protocols that were designed in such a way that the rotation in the executioners should not rebound negatively on the quality of the produced pieces or on the final result. The operations were simple and repetitive; anyone could take on the tasks of each work station after a very brief and short training. That was only possible due to the structure, the constructive elements and the work streams and the operations design that was configured for this purpose.

The experience of the La Casa de Marcello's assembly has made possible progress in the investigation and design modifications that would have been impossible without proceeding to the development of the construction of a full-scale project. Different aspects of the system were reconfigured, by amending the constructive elements and the assembly methods involved, reducing some operations and simplifying others. These changes were implemented for the construction of the following prototype built in June 2013 during the International Architecture Festival Eme3 demonstrating their opportunity and effectiveness in terms of employment of materials, time of assembly and simplification of the operations. All these experiences were eventually transformed into a teaching plan which was presented and was selected for the 34th Festival of the European Architecture Students Assembly, which was held in Bulgaria in August 2014. The workshop "Geodesic Geometry" (Fig. 1) had a sole mentor (Gianluca Stasi) and 13 students, its practical part consisted in the construction of a geodesic structure to donate to a local initiative at the end of the festival. The goal was twofold, to form a group of students from all europe and definitely check the technology accessibility protocols proposed for the Brujodesic constructive system.

Despite requiring an higher number of pieces (52 % more) and present a greater complexity regard La Casa de Marcello, the new structure, was built in similar times. This experience demonstrate the evolution of the proposed technology and of the production and assembly systems and its ability to allow a lonely person to empower quickly and efficiently a large group of persons, who are not familiar with the system, and direct the montage. At the end of the festival a student led the dismantling, the transport and the new assembly of the structure, demonstrating the effective and real empowerment provided during the brief duration of the workshop and the validity of the proposed protocols.

6 Barcelona, Spain. Design Ctrl+Z. Construction Ctrl+Z (Gianluca Stasi) and NoSoloPaja. Geodesic Dome v3, ø 4.4 m. NoSoloPaja.
7 Eme3, Festival on 27-30 June, Fabra y Coats Barcelona. Prised with the 3rd award of the festival.
9 It was attended by students of Belarus, Bulgaria, Spain, Finland, France, Moldavia, Poland, Portugal, Russia, Slovakia, Slovenia.
3.2 Flexible Rods models - Radial Union

And at the same time another work line for the "Radial Union - Flexible Rods" constructive system was developed. The two experiences did not walk independent paths, but they were feedback the one to the other in direct and indirect way.

This constructive system is based on linear elements that possess sufficient flexibility to adapt to the circular trajectories that are designed on curved surfaces. Depending on the level of flexibility, this could be excessive and thus negative, in fact this type of system is not very popular and there aren't many examples of its use to part of those produced by the presented research. In order to avoid the problem has been chosen to "knit", overlap, different geodesic domes on the same surface. In the absence of bibliographical references this geodesic systems have been named as "Woven Geodesic System". It the spherical surface specific case this is possible thanks to the duality property of the platonic solids used for the generation of the geodesic meshes, although there are, and can be applied, different strategies to approach to the issue. In January 2013 the first prototype was built in Brazil and the structural properties that brings knitting different geodesic geometries on the same surface were proved.

10 “Woven Geodesic System” conceived and designed by Ctrl+Z (Gianluca Stasi).
11 "The dual of a polyhedron has a vertex for each face and a face for each vertex of the original polyhedron" (Popko 2012).
In other experiences, we were able to verify how for the "Radial Union - Flexible Rods" constructive system, the considerations, the design and construction methods developed for spherical systems can be easily adapted to other geometries and other materials. At the same time the adaptability of the system to be implemented with non-trained personal was checked. In fact it was able to be applied immediately and without relevant modifications to the construction of two "Zomes", structures based on the Zonohedron\textsuperscript{13,14} (Spain March 2015 and Brazil July 2016) and two other based on the cilinder (Brazil September 2015 and Spain March 2016) these last two for the construction of water condensers (fogcatchers).

![Interior of the Zome realized in Brazil, July 2016.](image)

After those experiences the specific technology accessibility protocols for this constructive system were drawn. Those were implemented in two theoretical and practical workshop one in October 2015 in Málaga\textsuperscript{15} and the other in April 2016 in Sevilla\textsuperscript{16}. Prototypes were built in both occasion starting from pvc blinds slats. Málaga's prototype was donated to the "Asociación Jaulas Abiertas - Universidad en Transición" (Fig. 3) to implement a greenhouse at service of the orchard they manage.

\textsuperscript{13} Zonohedro: "In 3D space, a convex polyhedron whose faces are paralelogramas, each face has an even number of edges and each edge of each face is parallel to his opposite edge and each of its 2D faces have centers of symmetry" (Popko, 2012).

\textsuperscript{14} for example: Seville, Spain. Design Ctrl+Z. Construction Ctrl+Z and volunteers of the Huerta del Rey Moro. Geodesic Zome v14 ø 4,2 m. Pvc blinds structure.

\textsuperscript{15} Málaga, Spain. Workshop "Escala Local". Zome + Dome, ø 4.0 m.

\textsuperscript{16} Seville, Spain. Workshop cultural week Etsa Sevilla. Geodesic Dome, ø 4.0 m.
3.4 Rotegrity

The "Rotegrity" or "Nexorades" are a design, configuration and building of spatial structures and geodesic systems technique that due to the complexity of its design and structural features, was not included among the most suitable for the lowtech self-build of living spaces. Even more complex, and aesthetically very attractive, it's to combine these designs with the principles of the method of the “Woven Geodesic System”, this produces a new geometric configuration that we have named “Rotegrity Dual” (Fig. 4). Exactly for its complexity, we thought it was interesting to test the "strength" of the technological accessibility protocols that are the subject of our investigation, on the self-build of this type of structures.

Once the peculiarities and the characteristics inherent of the system were analyzed the existing protocols were adapted to the specific case. Their effectiveness was successfully tested in July 2016 during the construction of a first prototipo in Brazil (Fig 2). The construction has been carried out in two days with basic tools (machete, hand saw, drill) and untrained and not familiarized to the world of architecture and construction volunteers, without verifying incidences.
17 “Dual Rotegrity”: system conceived and designed by Ctrl+Z (Gianluca Stasi).

The positive result of this experience encourages us to give continuity to the preparation of another, much more ambitious and complex, whose preparation had begun in May 2016 in Seville. The dimensions of this new prototype will oblige us to the use lowtech systems for the elevation (of people or of the structure itself) and to handle pieces of greater dimensions allowing to definitely check the validity of the specific proposal and general protocols.

4 Conclusions

The results obtained in real experiences have allowed to verify and confirm empirically the consideration of the geodesic systems as sustainable and the importance of proper geometric configuration and the applicability of the of technology accessibility protocols designed specifically for the self-build and the use of these technologies and building systems in lowtech production environments. These have demonstrated their ability to adapt to the specific conditions of the territories and of the communities in which they have been applied. Being based on local materials and forming local workforce they promote the sustainability and the reproducibility of the proposals. Also, during these experiences, the iconic power and the imaginary generated by these geometries, jointly with the surprise promoted by the speed of their assembly, have contributed to attract the attention, add strength and increase the debate and the contributions around the proposed projects that, in the majority of the cases, had

social and independent character. There has been a positive effect on the self-esteem of the people involved and their bounds with the processes developed.

For this reason the objectives of the research are not limited to the resolution of technical issues; in the general framework of the project, those are intermediate steps and necessary support, the essential, in order to reach technological accessibility protocols.

The protocols can be used to achieve different constructive goals in very vary technological and geographical situations, using both materials of recovery as new ones, for which certificates of quality or the knowledge to interpret them correctly might not be available. Along with the relevant information about the characterization of the materials to use, will be necessary to accompany a guide on materials verification methods for the self-build, and give scientific support to their use. The verifications have to be designed to be carried out in the low-tech technological environment in which the investigation is developed.

The process will be completed with the edition of a graphic guide that will allow that the produced knowledge could easily and directly be available for those who need to apply the investigation's results without having to delve into the different phases of design and research.

Beyond its technical value, the results of this research aspire to be configured as a teaching and social tool, to empower communities, endowing them of the needed knowledge to take a leading role in the autonomous and independent resolution of some of their needs.

5 Bibliography

