

BAMBOO TENSEGRITY STRUCTURE: NEW METHODOLOGY FOR WHEELCHAIR DESIGN.

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Abstract

This research is inserted in the universe of people with special needs and intends to develop a new technology to design the structure of wheelchair. This structure consists of a tensegrity module composed of bamboo sticks and tensioned cables and adopts all the anthropometric standards with the observance to the ergonomic studies and individual needs of the use of the wheelchair users. This new concept of structure design, as it is unprecedented, results in an innovative product and allows new interpretations and unfolding. This research also initiates a new interpretation of tensegrity by its application to orthotics for rehabilitation that is currently widely diffused in the plastic arts, architecture, but incipient in product design. The use of tensegrity can meet some needs as a favorable body adaptation due to the malleability of the structure that absorbs the more sudden movements that can cause discomfort, injury and bad accommodation of the user to the wheelchair, besides providing a product of low cost and of easy production, because the structure is assembled by fit and wired.

Keywords: Bamboo, wheelchairs projects, tensegrity

Introduction

This research was the result of the doctorate of the author and had the objective to develop in the field of design, new technologies (methods and techniques) that manage its application in objects of utility from the tensegrity structure that is widely used in the field of the plastic arts and architecture, but incipient in product development projects. Therefore, it is attempted to develop a wheelchair design that makes use of the tensegrity structure, taking advantage of the spring effect that it has and which has been proven by Fuller's research.

The set of these tensegrity characteristics will allow a production without the need for rigid structures with metal welding and that, even in the scope of usability, add comfort and safety to the user of the wheelchair. The design methodology was based on ergonomic analysis for the development of the design of the test model and the production of the physical model for tests applied to wheelchair users.

The author of this research began his research in the area of rehabilitation still in the graduation of industrial design when he designed the stand-up wheelchair (figure 1), which has a mechanism that allows the user to stand independently. With this invention, the author opened a factory to produce the stand-up wheelchair, where he acquired specific expertise and knowledge in the wheelchair manufacturing process. This knowledge began as a starting point for his master's thesis entitled "Wheelchairs: a Design and Prescriptive Approach", where he can deepen the ergonomic and usability aspects in wheelchairs and subsequently make his doctorate possible.



Figure 1. Stand-up wheelchair (prepared by author)

ASPECT OF TENSEGRITY AND BAMBOO

In this chapter will be presented the human and basic conditions of the project that propitiated the execution and development of the tensegrity wheelchair.

ASPECT OF TENSEGRITY

Tensegrity is the name given to describe physical structures assembled by rigid sticks that do not touch each other and are kept in their place by traction cables. This name was given by Fuller (1995), an architect and scholar of this type of structure. In these structures, the parties not to support each other and are connected by flexible cables, produce the effect of spring, being that its main feature and observed in this research. There are some basic arrays of shapes of the system that it calls basic cell. Which were developed by Snelson (2015), as shown in Figure 2.

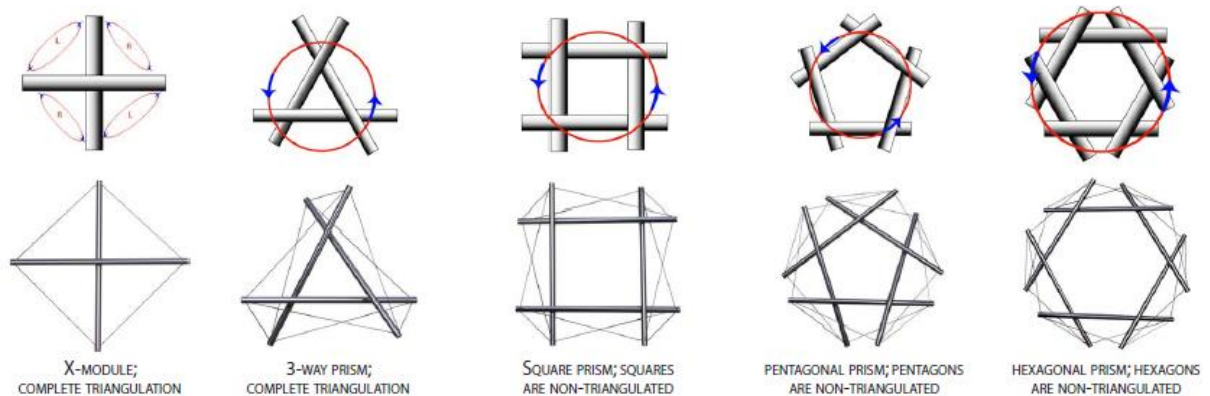


Figure 2. Cell combinations tensegrity (Snelson, biography)

This characteristic of being flexible was fundamental to the initiative of using a tensegrity structure in a wheelchair. The mechanical capacity of a tensegrity structure is notorious as well as, the cost benefit and weight, but it can be critical to the wellbeing of the wheelchair user. And it is on this aspect that was based one of the hypotheses and objectives of the research. The flexibility cannot be confused with loss of structural form, quite the contrary, the characteristic of tensegrity is always to return to its initial form after suffering some deformation. It is a perfectly elastic system, according to figure 3.

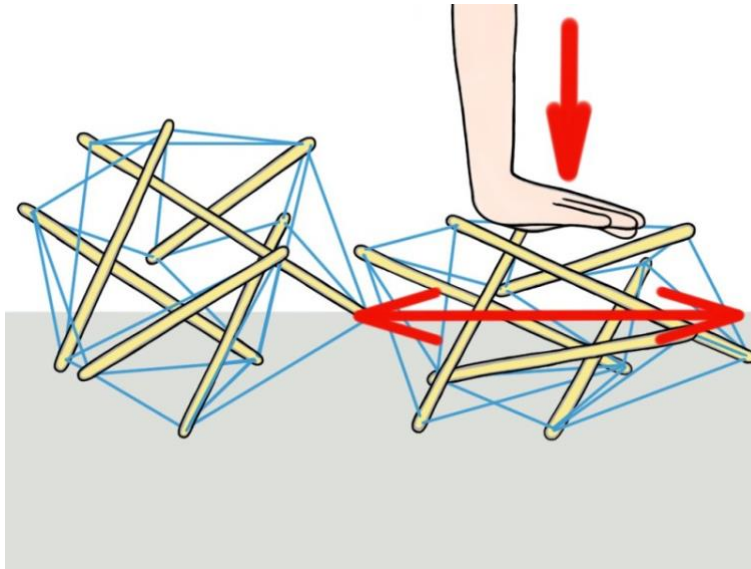


Figure 3. Demonstration of the malleability and resilience of the tensegrity structure (by author)

The engineer, architect and designer Richard Buckminster Fuller was the first scholar of these structures, now known as tensegrity, in the 1920s. One of his greatest contributions was the development of a spherical tensegrity (Figure 4) model that served as a starting point for other studies of his time onwards, becoming the main reference in this area.

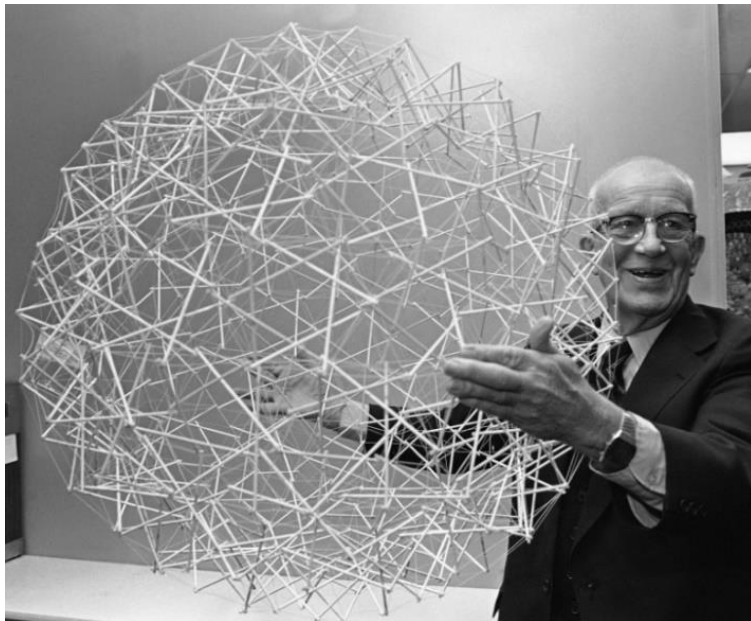


Figure 4. Tensegrity spherical (1927 – Fuller)

The model used in this research the steel cables are drawn and consequently compress the bamboo keeping the structure integrates perfectly adjusted as shown in figure 5. In item 3 it will be demonstrated because the tensegrity model chosen was the best option among several existing ones.

As the bamboos do not touch when the structure receives some pressure the whole structure (bamboo, steel etc.) is free to move and distribute the forces acting on the structure in order to cancel out its effects. Another important factor for the maintenance of the integrity of the structure is its resilience capacity, because when the forces cease the structure returns to its initial shape.

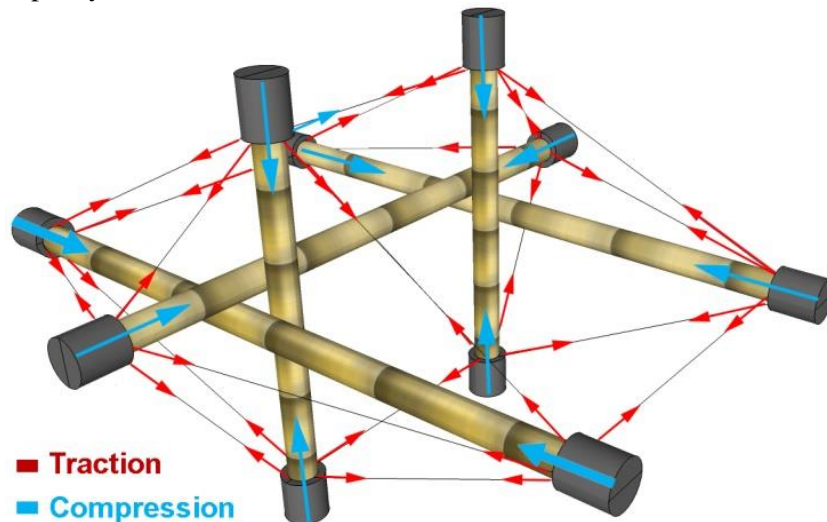


Figure 5. Distribution of forces in the tensegrity structure (by author)

According to Fuller (1995) these systems work in the light of a synergy where their behavior is not dictated by any of its components separately, but by the sum and cooperation, in the divergence and convergence of the parts for the same purpose. In Synergy the value of the set of components of the whole is greater than the value of each part individually.

ASPECT OF BAMBOO

To realize the benefits of the application of bamboo in relation to steel, for example, bamboo offers a tensile strength versus specific weight 2.77 times more than steel, as reported in the table below withdrawal of Gavami's research (1992).

Material	Tensile strength (Mpa)	Specific weight (gf/cm ³)	$R=(\sigma_t / \gamma)10^{-2}$	R / R steel
Steel	500	7,83	0,63	1,00
Bamboo	140	0.80	1,75	2,77
Aluminum	304	2,70	1,13	1,79
Cast Iron	281	7,20	0,39	0,62

Table 1. Tensile strength Ratio X specific gravity (1992, Ghavami)

Another advantage is the relationship between the specific weight Vs. resistance. A comparison based on production per unit of power voltage for building materials shows a bigger difference reaching 50 times, as shown in the table below withdrawal of Ghavami's research [6].

Material	Bamboo	Woody	Concrete	Steel
M/m3/MPa	30	80	240	1500

Table 2. Power Relationship of production per unit of voltage (1992, Ghavami)

Bamboo is a tropical plant that has a renewable annual cycle of reproduction without the need for replanting, in addition to being the natural resource that is renewed in less amount of time, in the absence of any other species of forest plant that can equate in growth rate and of for planting area. For these features bamboo is a great agricultural potential and that consequently presents itself also with great potential for application in large scale by industry. In addition to being an efficient carbon fixation, has excellent physical, chemical and mechanical characteristics.

METHODS OF PROJECT DEVELOPMENT

For the development of the tensegrity structure, a tensegrity model developed by the doctoral advisor (Figure 6) prof. Ripper in the 1970s. The chosen model has already been the subject of successful research in other opportunities for making tents and tents, but never for the design of a wheelchair. The definition of the model was given by the physical characteristics since they combine with the structure and needs of a wheelchair. The necessary parts (wheels etc.) fit perfectly, as can be seen in the descriptions in the following set of images.

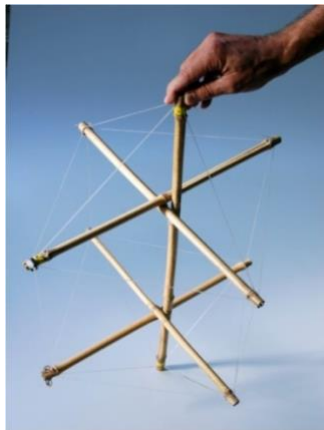


Figure 6. Tensegrity original of Prof. Ripper (prepared by author)

Set the tensegrity module the project focused on defining a position coincide the anchoring points of the set of use (set the backrest, seat and footrest in metal) with the sticks of tensegrity module, and tensegrity allows a multitude of positions that can be seen in three dimensions which makes the definition of the ideal position. So, the first step was to analyze the two structures, tensegrity and set to use, and check the possible coincidences. Forming itself and especially the front wheels provided the path to follow. The front wheels are positioned parallel to the front of the wheelchair and the tensegrity module has two pairs of parallel rods. From that coincidence both configuration structures, were attempted a series of positions to find the ideal position. One of them was to position the tensegrity module horizontally so that pair of parallel rods stay parallel to the ground, as shown in figures 7 and 8.

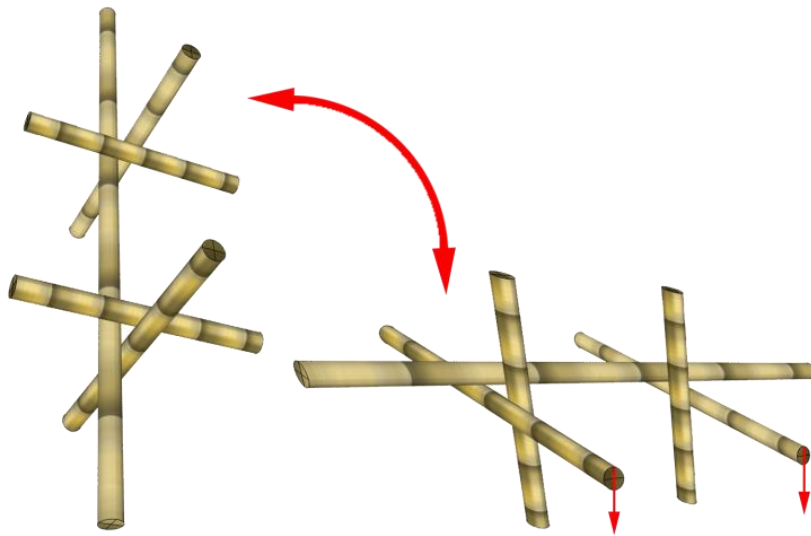


Figure 7. Tensegrity rotated parallel shafts down coincident with the front wheels (by author)

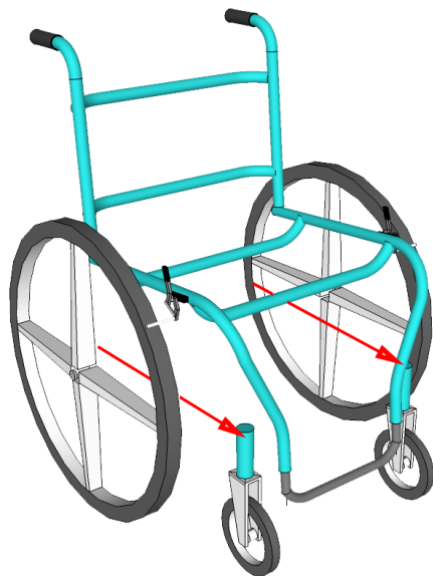


Figure 8. Coincidence of the front wheels position with parallel rods (prepared by author)

The drop seen in the previous figure, not only defined the coincidence of the sticks with the front wheels, but stressed also the positioning of tensegrity fitting with the set of use at the top by the position of the other two parallel matching bamboo stalks, as shown in figures 9 and 10.

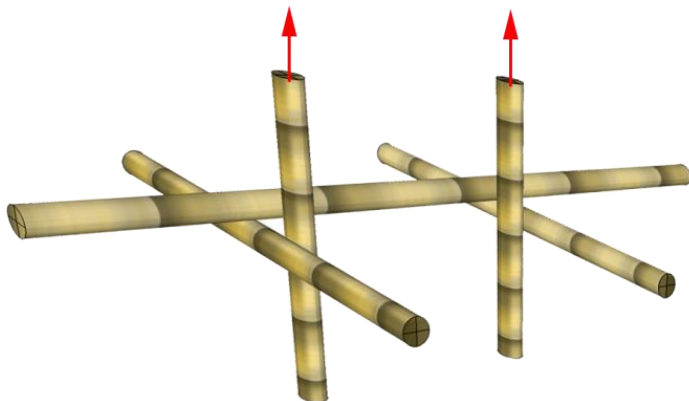


Figure 9. Tensegrity Module with coincidence of vertical bamboo poles with the use (by author)

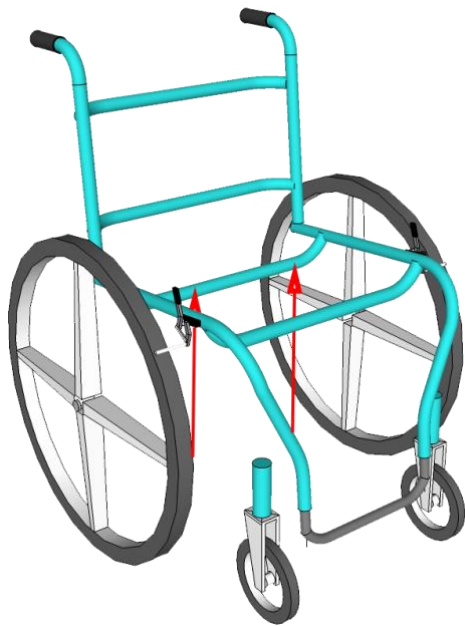


Figure 10. Coincidence of the seat frame position with the uprights (prepared by author)

This second placement match also showed another possibility of coincidence in the pair of rear wheels with the last bamboo rod that is positioned transversely on the tensegrity module (figures 11 and 12) and waxed the dimensions and successfully docking between the structures of the set of use with tensegrity module.

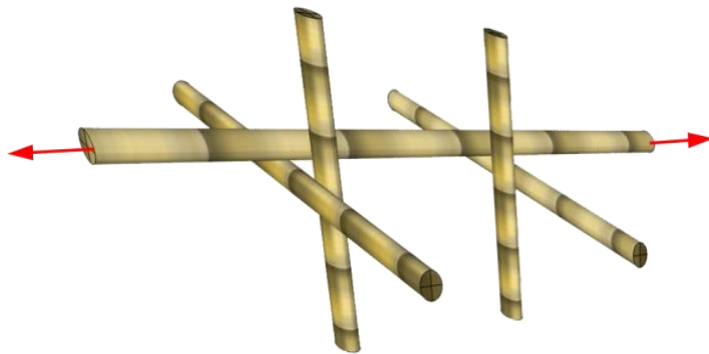


Figure 11. Tensegrity module with bamboo rod with fitting the rear wheels (by author)

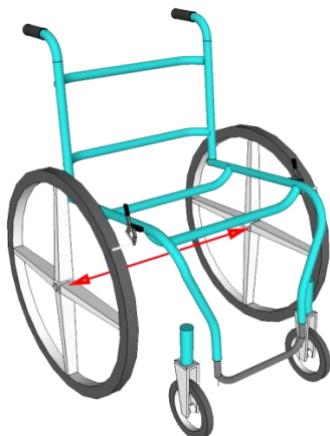


Figure 12. Coincidence of the position of the rear wheels with the transverse rod (by author)

The next step was to carry out the dimensioning of the bamboo rods to adjust to the use that has measures for users with stature between 1.60 to 1.70, as shown in figure 13.

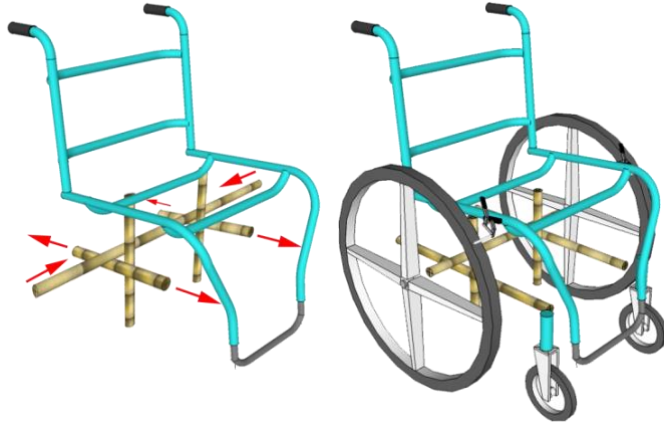


Figure 13. Tensegrity Module adjusted to the use (prepared by author)

The design of the wheelchair tensegrity is with use and the tensegrity module attached and adjusted, ready to be finalized with the basic use items like brakes, armrests, seat and backrest tarps and the footrest. The set developed in digital 3D application can thereafter the development generate detailed technical drawings of manufacturing will give subsidies to make up the test template and feedback the test model itself, according to chapter 4 of the thesis. [8].

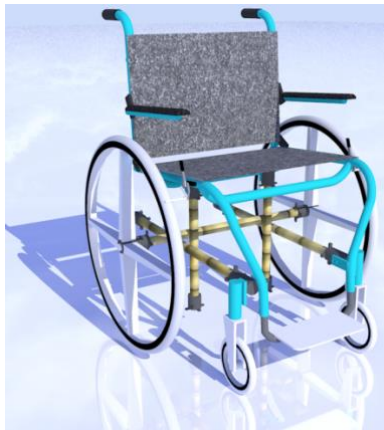


Figure 14. Prototype design the wheelchair of tensegrity structure (prepared by author)

METHODS OF PRODUCTION OF THE PROTOTYPE

For the production of the test model was developed a template which formed the basis for the use of metal set, consisting of the backrest, seat and footrest, with tensegrity structure of bamboo, according to chapter 5 of the thesis. [9].



Figure 15. Set using the standing wheelchair (prepared by author)

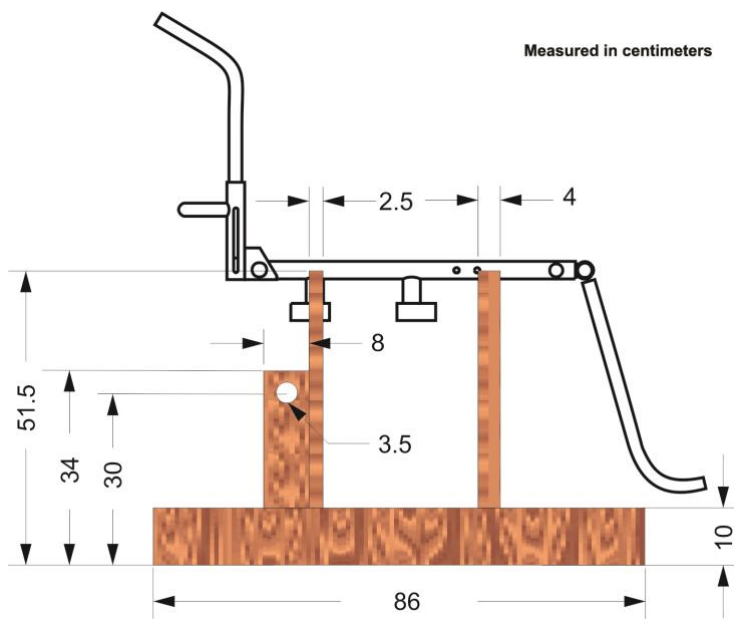


Figure 16. Technical drawing of the template for the set of use (prepared by author)

After defining the measures and positions as the technical drawing was started the production of the feedback of the parties that are the holders of the bamboos of tensegrity structure. This step before the final Assembly of cables. Therefore, it is extremely important that is held within the stipulated specifications. With the cabling terminated the manufacturing phase of the test model was completed successfully, set the application methodology of the tests.



Figure 17. Gauge ready with the five rods positioned (prepared by author)

After the production of the metal connections, which will serve as the anchor cables, has begun the final Assembly of the model for the cabling.



Figure 18. Gauge mounted with metal rods and connections and tensegrity structure wired (by author)

With the cabling terminated the manufacturing phase of the test model was completed successfully, set the application methodology of the tests.



Figure 19. Test model of the wheelchair of tensegrity structure - prepared by author

DISCUSSION AND EVALUATION OF TESTS

To structure the tests was chosen qualitative research technique called-action-research-that best shapes the needs and specifics, because this technique interferes with the field researcher where the research takes place, along with interlocutors present, i.e. There is a cooperation between the participants to solve the problem.

For the application of the practice tests, was designated by the technical advice of CVI/PUC-Rio [10], the test model of tensegrity Chair should be used by the user in your home and/or places of their daily lives to perform all functions and routine actions for two days.

With respect to the analysis of the practical tests was defined that users should make a comparison between using their wheelchairs (activity of daily life) of rigid structure, with the test model tensegrity. Thus, users would have a parameter where analysis could evaluate the research questions in the questionnaires, which were defendants applied after the two-day trial. The interviews, if there is availability of user, would be carried out on the premises of CVI/PUC-Rio with the presence of a multidisciplinary group and so manage the result. The test user (1), the advisor (2), the researcher and a CVI commission with the clinical body composed of the Therapist (3) and the Designer (4), the CEO of CVI/PUC-Rio (5) and two guests medical rehabilitation students (6 - 7) were present, according to figure 20.



Figure 20. Multidisciplinary group on CVI/PUC-Rio (prepared by author)

Thus, a detailed research process was set up to organize and order the sequence of practical tests with the user to obtain the best data.

1 - Creation of questionnaire for cataloging of reports from users of wheelchairs in use of wheelchairs post-tests.

2 - Choice of wheelchair users by criteria and indicate the CVI/PUC-Rio.

3 - Application of tests with users to study the behavior of physically handicapped persons to the functional model simulating situations of daily use in the home of the person who will perform the test.

4 - Analyses of comparisons between the use of tensegrity Chair with the Chair of the user himself.

5 - Collection of the results of the practical and theoretical studies through study group composed of the supervisor of the research, the researcher, the wheelchair user and the professional group CVI/PUC-Rio.

Note: In items 3 and 5, at the time of the tests, if authorized by the author, some photos and / or videos may be collected for cataloging.

The three people who tested the wheelchair tensegrity (Figure 21) gave a favorable opinion on the question of the structure absorb impacts and provide thus greater comfort. All participants signed the term of free consent, as well as the authorization for disclosure of their names and images in scientific publications.

Figure 21. Group of wheelchair users who performed the tests (prepared by author)

User Information	User-defined user descriptions
 <p>Woman with active 33 years drives cars and works</p>	<p>The first user to test the tensegrity structure was a. At first, the chair seemed strange to him by the visual aspect, but with the use in his residence he realized that the structure acts as a shock absorber and the sensation is very good and it helps to those who need to spend much time sitting in a chair to get around. By the end of the test, she had grown accustomed to the chair, and she already thought she was so strange.</p>
 <p>Active 45 year old man drives cars and works</p>	<p>Made an important caveat regarding a small bump between the kitchen and the hallway that with his daily and private chair needs to perform a small maneuver by poking the front of his chair so that the wheels the front pass over. Already with the tensegrity chair he was able to transpose the rebound without the need for any extra maneuver and also did not feel any impact that would impair the handling of the chair or cause him any discomfort. He completed this analysis with an observation regarding the strength of the tensegrity structure, saying that even performing the task of transposing the rebound the structure seemed extremely strong and did not suffer any misalignment after the action, as well as, it remained very compact every day of tests.</p>
 <p>68-year-old doctor and 42 years of age using a wheelchair. The Doctor is a pioneer in the game of tennis for wheelchair users in Brazil, including participating in several Paralympics and constantly invited to give lectures on this theme.</p>	<p>The Doctor is a pioneer in the game of tennis for wheelchair users in Brazil, including participating in several Paralympics and constantly invited to give lectures on this theme. Due to physical problems arising from many years of wheelchair use it is very difficult and painful to adapt to other wheelchairs and perform the tests. However, with his experience in developing wheelchair designs, Doctor contributed directly to the project suggesting several changes in the design.</p>

CONCLUSION

At the end of the research we have come to the conclusion that all the questions presented as the problem of research objectives: General and specific, and the hypothesis formulated were correct and have been proven by tests. Thus, the conclusion is that the research is justified and is able to provide academic and social developments in the field of assistive technology and rehabilitation and still be applied in similar products in the structural and functional aspects that are moved the wheels.

It is considered as hypothesis that the use of the principle known as tensegrity can be integrated and applied in the design of wheelchair meeting the usability needs of the user, making this a structural extension of the body interacting organically absorbing impacts, since tensegrity is a cable spring and bars for greater comfort.

Based on the results obtained in the research, after tests with users and discussions with the multidisciplinary group of professionals in the field of rehabilitation, were generated numerous suggestions and contributions to suit the design of the project needs and practices of use, as well as to new technologies and materials in the production of wheelchairs, all with the aim of improving the quality of life of the user. It was also possible to envision the possible consequences of the initial project, done for the test model, which resulted in some proposals to the Chair design and can be observed in the conceptual design proposals (Figures 22, 23, 24).



Figure 22. Conceptual proposal in natural bamboo (prepared by author)



Figure 23. Concept proposal in colored bamboo (prepared by author)



Figure 24. Hybrid conceptual proposal of metal and bamboo (prepared by author)

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REFERENCES

Stand-up Wheelchair, Online available from - <http://www.pessoaldesign.com/>

Kapandji, I. A.. Articular Physiology . Rio de Janeiro: Ed. Guanabara Koogan, 2009.

Chapter 2 of the thesis - Wheelchair with Structural Design in Tensegrity Bamboo, Online available from http://www2.dbd.puc-rio.br/pergamum/tesesabertas/1413459_2016_cap_2.pdf

Fuller, R. B.. Synergetics: Explorations in the Geometry of Thinking, Carrier Mamillan Publishers, London, 1995.

Tensegrity, weaving and the binary world, Online available from https://smiadotexperimentalldotcom.files.wordpress.com/2015/01/snelson-tensegrity_and_weaving.pdf

Ghavami, K.. Bamboo: An Alternative Material in Engineering. The Journal of the Institute of Engineering, PUC 492/1992. Ingenuity, Technical Editor Ltda, São Paulo, p. 3-7.

Ripper, J. L. M.. Society, Nature and Technique: Design of Adaptive Structures of Bamboo. Rio de Janeiro, 2015.

Chapter 4 of the thesis - Wheelchair with Structural Design in Tensegrity Bamboo, Online available from http://www2.dbd.puc-rio.br/pergamum/tesesabertas/1413459_2016_cap_4.pdf

Chapter 5 of the thesis - Wheelchair with Structural Design in Tensegrity Bamboo, Online available from http://www2.dbd.puc-rio.br/pergamum/tesesabertas/1413459_2016_cap_5.pdf

CVI-PUC-Rio - Independent Living Center of the Pontifical Catholic University of Rio de Janeiro, Online available from www.cvi-rio.org.br

Chapter 6 of the thesis - Wheelchair with Structural Design in Tensegrity Bamboo, Online available from http://www2.dbd.puc-rio.br/pergamum/tesesabertas/1413459_2016_cap_6.pdf

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