RESEARCH ARTICLE OPEN ACCESS

Numerical analysis of lobular structures for biomimicry of a mammary gland structure

Francisco Josué Hernández Rangel[1,3], Adriana del Carmen Gallegos Melgar[2], Azahel de Jesus Rangel Lopez[3], Pedro Cruz Alcantar[3]

[1]*Estudiante de Posgrado CIATEQ, A.C., Centro de Tecnología Avanzada., Eje 126 no. 225, Zona Industrial del potosí, San Luis Potosí, San Luis Potosí, C. P. 78395, México*
[2]*CONACYT, Corporación Mexicana de Investigación en Materiales, CP 25290 Saltillo, Coahuila, México.*
[3]*Departamento de Ingeniería Mecánica y Mecatrónica. Coordinación Académica Región Altiplano (COARA) de la Universidad Autónoma de San Luis Potosí (UASLP). Matehuala, San Luis Potosí, México. CP.78700.*

ABSTRACT
The mammary gland is an organ that has an internal structure formed by lobules, ducts and ligaments that perform both physiological and mechanical functions. This structure aesthetically defines the body and has the additional function of producing milk in mammals to support offspring. Currently, structures and shapes are being studied to imitate the nature of the mammary gland for medical applications such as prostheses, systems and models for surgeries, the most used technique for this is biomimetics. There are no models or devices that contemplate the internal structure of the mammary gland, so in this work different structures that imitate the lobular adjustment found in a real mammary gland are proposed, these structures were subjected to different load states to numerically evaluate and optimize the proposed structures. It was found that the triangular or lobular structures have better behavior in the distribution of deformations and stresses being excellent candidates to be part of biomedical applications.

Keywords - biomimetics, biomedical structures, mammary gland, numerical analysis

---

Date of Submission: 15-10-2022 Date of Acceptance: 31-10-2022

I. INTRODUCTION

There are different structures in the breast that provides support and help maintenance the form in the mammary gland. The principal structure is composed for 15 to 20 sections called lobes, this structure contains the lobes, lobules, and the bulbs, there are all connected by thin ducts, which connect in the nipple, fat fills the spaces between the lobules and the ducts, A main structure is the glandular tissue, in which bundles of small bodies known as lobes are found [1]. There is currently great interest in mimicking the mammary gland for medical applications such as prostheses or models for use in surgery. There is currently great interest in mimicking the mammary gland for medical applications such as prostheses or models for use in surgery. One technique that can be used to mimic the nature of a mammary gland is biomimetics. The Biomimetic is the science that mimics the structures and materials found in nature to produce new structures and better materials that resemble those found in nature, the Biomimetic endeavors to understand how life functions on different levels, imitating the structures and organisms found in nature with the aim of creating new structures, new

materials, and new products-based mainly on nature [2-3].

In the literature there are various scientific and technological advances that provide computational models focused on simulating the mammary gland for diagnosis and planning surgeries and medical procedures [4] or analyze biomaterials used for implants in reconstruction [5-6] However, anybody considers the internal anatomy of the breast in computational model's (biomimetic).

Therefore, this work proposes the analysis of 3 structures that mimic the lobular adjustment that exists in a real mammary gland so that the mechanical behavior is similar to the real one, in the first part of the work, they are proposed: a triangular structure, a rectangular structure and another similar, but with rounding in the corners, in addition the 3 structures were adjusted to a spherical region proposed to delimit and distribute loads in the lobular zone.

In the second part of the work, different load states that a mammary gland experiences during the day are proposed. Subsequently, they are analyzed with finite element to evaluate the stress and deformation experienced by the structures after applying the load states.

II. MATERIALS AND METHODS

One of the main contributions of this work is to determine the best geometric shapes to mimic or biomimicry the internal structure of a real breast or mammary gland for applications in biomedical devices such as breast prostheses, systems, and models for surgeries. Biomimetics tries to understand how life works at different levels, biomimetics mimics the structures and organisms present in the nature to create new structures, new materials and products based mainly on nature [7]. In the breast there are different structures to support the mammary gland. The main structure is identified as the glandular tissue structure in which small bodies known as lobules are grouped. Therefore, three structures will be proposed that will try to imitate the set of lobules found in a real breast. The proposal of this type of structures aims to use simple shapes that mimic the lobular fit of the breast, in order to facilitate their design and fabrication.

The lobe distribution was placed within a circular setting to take advantage of the qualities of this setting with respect to deformation fields and stress distribution, it is well known to be used when it is required to obtain a uniform distribution of loads or stresses in components [8]. The lobular cavities gradually increase in size as they approach the backside. The arrangement also has an element of connectivity with the nipple, as in the real lobular arrangement following the pattern of the petals of a daisy.

The first proposed structure is a triangular or lobular shape that will be compared with various rectangular structures in order to verify how it behaves in the load cases designed for the study. The proposed structures are shown in Figure 1.

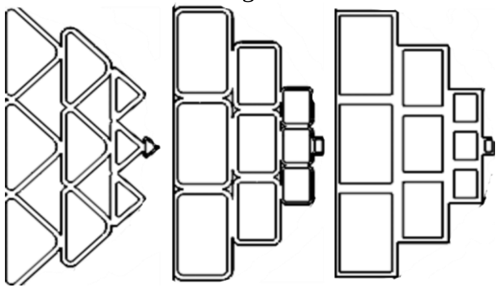

Figure 1. Internal structures proposed for analysis

For each structure different distributions and sizes of the geometric figures were proposed. A setting of 3, 4 and 5 bottom elements was proposed, and so their distribution gradually increasing in size as they approach the back, just as in the real lobular arrangement following the pattern of the petals of a daisy by the circumferential contour. Figure 2 shows the proposed distributions.

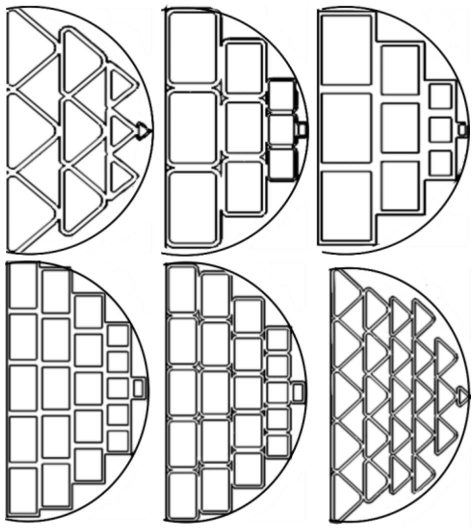

Figure 2. Proposed internal structures for analysis within circumferential fit.

For the numerical simulation with finite element, a plane 182 element of the triangular type was used since it is a geometry with irregular shapes and small areas, the most suitable element to simulate and allow the fastest coupling between these sections.

This element allows to simulate plasticity, hyper-elasticity tensile stiffness large deflection and large deformation capacity [9].

For the material, fibro-glandular fabric properties were used with the following properties: density 1020 kg/m3, Young's modulus: 1875 KPa and Poisson's Coefficient 0.49 [10]. In addition to geometric structures, load state cases were also proposed to evaluate the behavior of structures in terms of stresses and deformations. A good behavior of a structure will be equivalent to a behavior closer or more natural to that of a real breast. These load states are shown in the following Figure 3, the force applied was 5N [11].

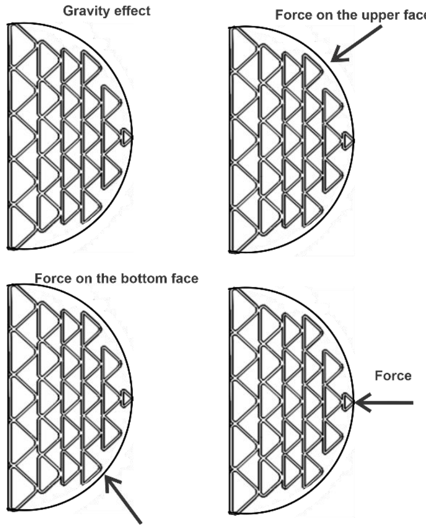

Figure 3. Load states to evaluate the proposed structures.

III. RESULTS

3.1 Static analysis in proposed 2D structures.

Case 1: Load state- gravity effect.

For the first case of load states, the proposed structures of the internal part were subjected only to the gravity effect. The gravity effect is the predominant state in any structure, in figure 4 the behavior of these structures is observed and the following can be observed: a) the loads are not distributed along the geometry they are concentrated in the corners this will cause the material to be damaged much faster in these areas, and b) it is observed that by adding roundings to the geometry it is possible to distribute the stresses a little more along the geometry but they are still concentrated in these areas. In Figure 4c) the same gravity effect load was applied to the triangular geometry (lobular) and it is observed that in this structure the stresses are distributed along the geometry and the stress concentration is minimal.

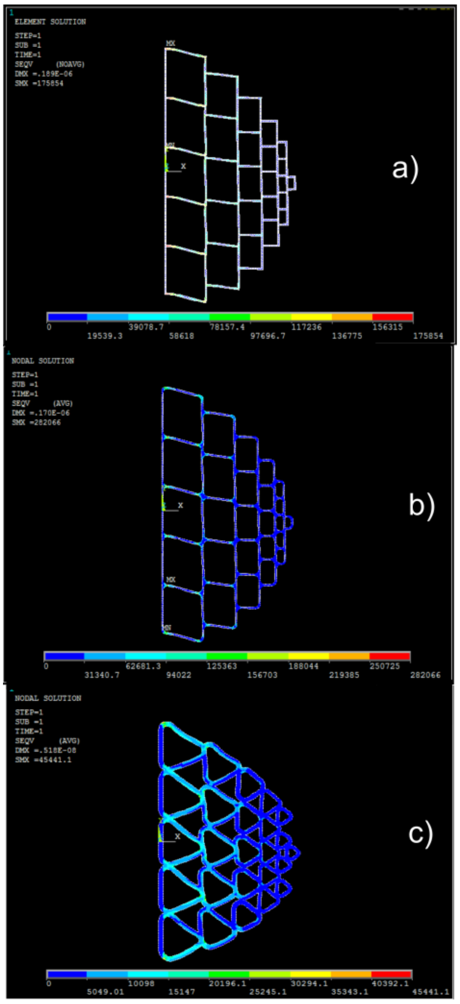

Figure 4. a,b) Rectangular and rectangular structures with rounded edges and c)Triangular structure (Lobular) subjected to gravity effect.

Case 2: Load state - horizontal force (sensitivity).

The second loading state considered was the application of a horizontal force to the different structures. In Figure 5 a) the rectangular structure without roundings concentrates the forces to a large extent in the direction in which the force is applied, this effect is not desirable for the structure and in the case of Figure 5b) the rectangular structure with roundings shows a similar effect, the forces, although they have decreased in magnitude, continue to be concentrated in the direction in which the force is applied. Figure 5c) shows the same horizontal force loading state now applied to the triangular (lobular) geometry. In this structure the forces are not concentrated and a greater distribution in the structure is achieved. In smaller magnitudes this is a desirable effect for the design since this way the wear on the prosthesis will be lower.

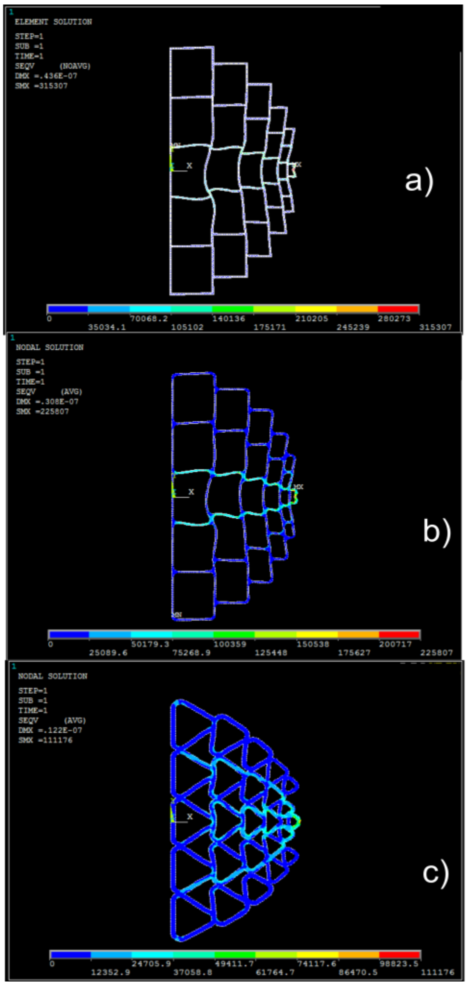

Figure 5. a,b) Rectangular and rectangular structures with rounded edges and c) Triangular structure (Lobular) subjected to horizontal force (sensitivity).

Case 3: Load state - force on upper face (sensitivity).

A third proposal for the load state considered was the application of a force on the upper face exerted to the different structures; as can be observed its behavior is similar to case 2 as shown in Figure 6. In Figure 6 a) the rectangular structure without rounding concentrates the efforts in the same way as the previous case in the direction in which the force is applied. In Figure 6 b) the rectangular structure with roundings shows a similar result since the stresses decrease in magnitude but are still concentrated. In Figure 6 the state of force load on the upper face applied to the triangular geometry (lobular) is better distributed than in the other types of structures.

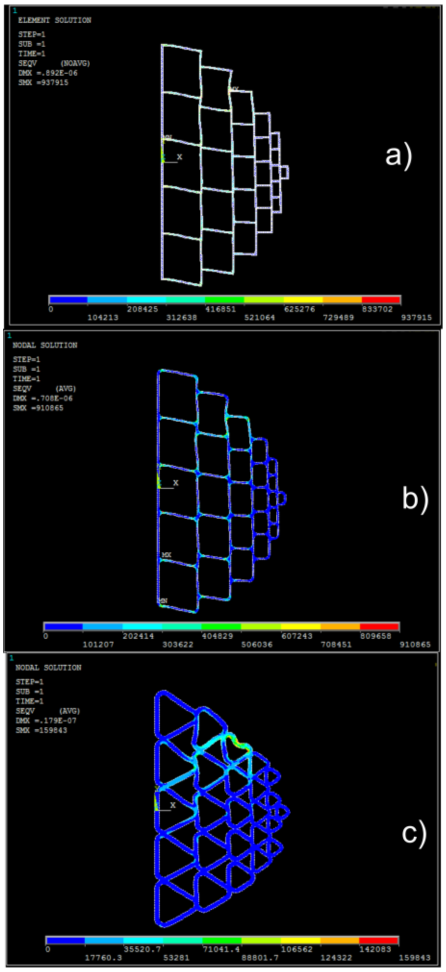

Figure 6. a) Rectangular structures, b) rectangular with rounded edges and c) triangular structure (Lobular) subjected to force on the upper face (sensitivity).

Case 4: Loading state - gravity effect and horizontal force.

The fourth load state considered was a combined load state of gravity and horizontal force; this load state is another of the predominant and main load states in any structure. The behavior of the structures in this case is shown in Figure 7 a) and b) corresponding to the rectangular and rectangular structures with roundings; it can be observed that they continue with similar behaviors to the previous cases where the loads are still concentrated in considerable and unfavorable measures for the design proposed in this work. Figure 7 shows the behavior of the triangular geometry (lobular) in the combined load state, in this structure the stresses are distributed along the entire geometry without presenting considerable concentrations due to the loads.

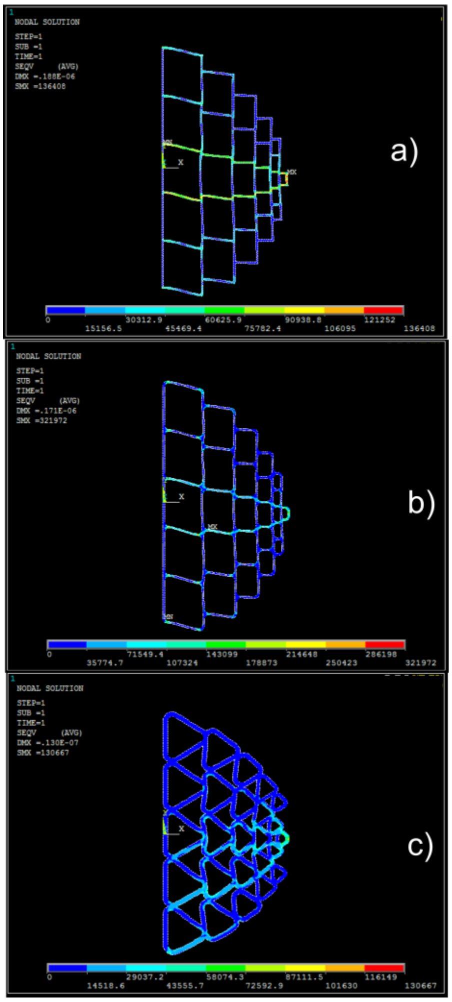

Figure 7. a) Rectangular structures, b) rectangular with rounded edges and c) triangular structure (Lobular) subjected to combined horizontal force and gravity loads.

Case 5: Loading state- effect of gravity and force on upper fase

In the fifth load state, the stress concentration in the rectangular and rectangular structures with roundings is still present in considerable measures along the structure; this combination of load states of force on the upper face and gravity causes the stresses to appear in different places from the previous cases, which is important for the design; the results obtained for these structures are shown in Figure 8 a) and b). Figure 8 shows the results obtained by applying this combination of loads in the triangular structure (lobular). In comparison with the other structures, this structure is the optimum for the design since it manages to distribute the forces over a larger area and with smaller magnitudes than in the other structures, which guarantees that it will last longer, and the solid materials will not collapse due to the loads.

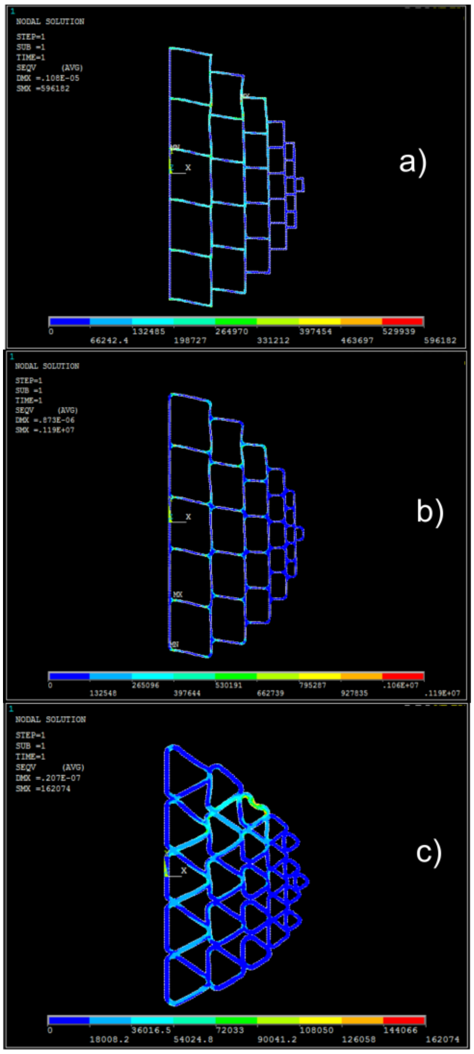

Figure 8. a) Rectangular structures, b) rectangular

with rounded edges and c) triangular structure (Lobular) subjected to combined loads force on top face and gravity.

IV. DISCUSSION

As part of the parameterization process, 3 arrangements with different dimensions and distributions were proposed. These arrangements were subjected to the same load case where the force is placed at the center of the circumferential fit.

For the case of the geometries with 5 elements (Figure 9), the deformation when the load is applied affects considerably the rectangular structure since the deformation reached is 0.02 mm 2.2 e-6 although it is much lower than the other geometries that reach deformations of 6.5 e-6 and 2.85e-5 respectively, but said deformation in the first two cases is concentrated and in the case of the triangular structure the deformation is distributed over the whole geometry and not only in the first element.

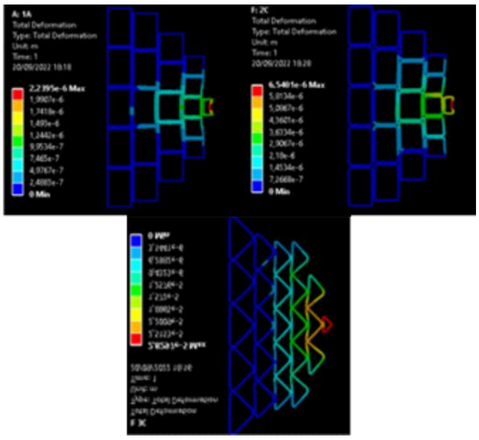

Figure 9. Structures with 5 lower elements: Rectangular structures, rectangular with rounded edges and triangular structure (Lobular) subjected to combined loads force on top face and gravity.

Figure 10 shows the structures with 4 lower elements the deformation in this element is 3.86e-6. and 5.57e-6 m respectively. In the first two cases the image shows how the deformation occurs at the edge of the first element and in the case of the triangular geometry although the elements of the first 2 rows are displaced 6.74e-6 m maintain their shape distributing the displacements without concentrating.

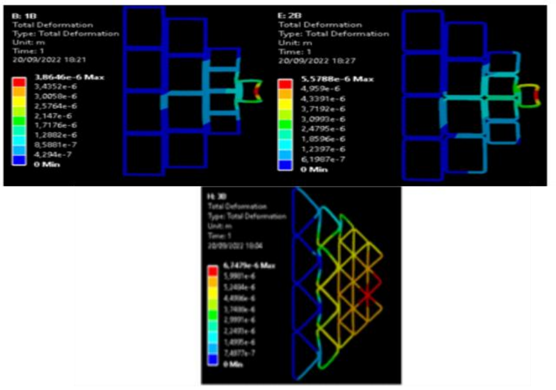

Figure 10. Structures with 4 lower elements: Rectangular structures, rectangular with rounded edges and triangular structure (Lobular) subjected to combined loads force on top face and gravity.

The last Figure 11 with 3 lower elements shows for the rectangular geometries a deformation is 2.08 e-6 m and 1.2 e -5 m in the first element, in the case of the triangular geometry the displacement is greater with a dimension of 1.52 e-5 m in the first two rows of elements are displaced together maintaining their original shape in greater proportion than the previous structures so at no time is the geometry or its structural stability compromised. After analyzing the effect of the point load in all cases, the triangular structure maintains its shape, absorbing most of the applied force and distributing it among a greater number of elements.

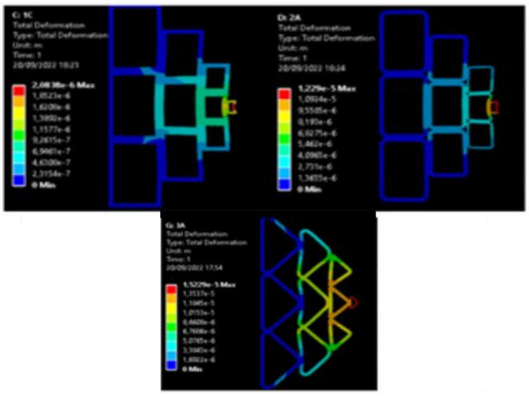

Figure 11. Structures with 3 lower elements: Rectangular structures, rectangular with rounded edges and triangular structure (Lobular) subjected to combined loads force on top face and gravity.

V. CONCLUSION

The conclusions resulting from this work are the following:

- The proposed geometries, being simple shapes easy to manufacture, present acceptable results since they all present results in a range of 138 KPa and 600 KPa which are well below the elastic limits of the material in this case glandular tissue which is 1875 KPa [10].

- The proposed sizes of 26 lobular elements and those of 10 elements mimicking the lobular setting is an optimal size that can be easily adapted to the internal part of the breast.

- The proposed load states showed that the case where the geometry suffers higher stress in the point load on the nipple where the geometry could be considered at risk, although the deformation values are well below the yield limit of the material with values from 138 KPa to 210 KPa is a load case to be considered in order to avoid it.

- Regarding the comparison of the proposed models (Rectangular, rectangular with rounded corners and triangular) it is verified that the geometries that do not have stress concentration (corners). The triangular structure distributes over a larger area.

- The triangular geometry turned out to be the geometry that adapts better to the proposed sphere since with this type of geometry the space is considerably optimized covering a larger area, besides being the structure that distributes the efforts mostly over its entire extension, it turned out to be the best option for the final proposal.

REFERENCES

[1]. A. Darlington, Anatomy of the Breast. In Digital Mammography: A Holistic Approach; Springer: Cham,Switzerland,; Chapter 1; 2015, 3–10.

[2]. M. Fernandez, S. Akogwu, L. McNamara, D. Zeugolis, A. Pandit,and M. Biggs, Biomimetic approaches in bone tissue engineering: Integrating biological and physicomechanical strategies, Adv. Drug Deliv, 84, 2015, 1–29.

[3]. H. Saal, and S. Bensmaia, Biomimetic approaches to bionic touch through a peripheral nerve interface, Neuropsychologia, 79, 2015, 344–353.

[4]. T. P. Babarenda Gamage, D. T. Malcolm, G. M. Talou, A. Mîra, A. Doyle, P. M. Nielsen, and M. P. Nash, An automated computational biomechanics workflow for improving breast cancer diagnosis and treatment, Interface Focus, 9(4), 2019, 1-12.

[5]. A. Mîra, A. K. Carton, S. Muller, and Y. Payan, A biomechanical breast model evaluated with respect to MRI data collected in three different positions. Clinical Biomechanics, 60, 2018, 191-199.

[6]. N. G. Ramião, P. S. Martins, R. Rynkevic, A. A. Fernandes, M. Barroso, and D. C. Santos, Biomechanical properties of breast tissue, a state-of-the-art review. Biomechanics and modeling in mechanobiology, 15(5), 2016, 1307-1323.

[7]. N. J. Iguarán, and O. J. Ramírez, Biomímesis: una propuesta ética y técnica para reorientar la ingeniería por los senderos de la sustentabilidad, Gestión y Ambiente, 19(1), 2016, 155-166

[8]. A. Lee, J. F. López, J. Marthelot, J. W. Hutchinson, and P. M. Reis, The geometric role of precisely engineered imperfections on the critical buckling load of spherical elastic shells. Journal of Applied Mechanics, 83(11), 2016, 1-11

[9]. S. Lokhande, T. Shende, S. Aher, and B. Indurkar, Project Report on Deep Beam Analysis using ANSYS, International Journal of Science Technology & Engineering, 4(12), 2018, 41-49.

[10]. C. Xue, F. H. Tang, C. W. Lai, L. J. Grimm, and J. Y. Lo, Multimodal Patient-specific registration for breast imaging using biomechanical modeling with reference to AI evaluation of breast tumor change Life, 11(8), 2021, 747.

[11]. P. Cruz, F. J. Hernandez, M. L. Zuñiga, J. M. Rodríguez, R. Figueroa, A. Vertiz, and Z. Pineda, A biomimetic approach for designing a full external breast prosthesis: post-mastectomy, Applied Sciences, 8(3), 2018, 357.