PRODUCTION OF SURGICAL BIOMODELS TO SUPPORT SURGERY BY 3D PRINTING: A SOCIAL AND ECONOMIC EVALUATION FROM THE DESIGN FOR SUSTAINABILITY PERSPECTIVE

PRODUÇÃO DE BIOMODELOS CIRÚRGICOS DE APOIO À CIRURGIA POR IMPRESSÃO 3D: UMA AVALIAÇÃO SOCIAL E ECONÔMICA NA PERSPECTIVA DO DESIGN PARA A SUSTENTABILIDADE

IMPRESIÓN 3D PARA LA PRODUCCIÓN DE BIOMODELOS DE SOPORTE QUIRÚRGICO: UNA EVALUACIÓN SOCIAL Y ECONÓMICA DESDE LA PERSPECTIVA DEL DISEÑO PARA LA SOSTENIBILIDAD

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ABSTRACT
This article presents, describes, and evaluates, from the perspective of Design for Sustainability (DfS), the social, economic, and technological aspects of the process of developing and manufacturing anatomical biomodels to support surgery using 3D printing in a Brazilian public hospital. This process had an interdisciplinary character, involving professionals of Design, Odontology, and Physiotherapy. The assessment was carried out using DfS (Design for Sustainability) social and environmental heuristics (guidelines), and enabled the identification of relevant aspects, as well as opportunities for improvement in processes. Among the results, the importance of having a specific space dedicated to digital manufacturing in public hospitals stands out, which speeds up the development of biomodels, as well as the quantity, diversity, and quality of 3D printing equipment, which allows the exploration of multiple possibilities for processes and materials, speeding up innovation in the hospital environment.

KEYWORDS
Public health; surgery; biomodels; 3D printing; product design.

RESUMO
Este artigo apresenta, descreve e avalia, sob a perspectiva do Design para Sustentabilidade (DfS), os aspectos sociais, econômicos e tecnológicos do processo de desenvolvimento e fabricação de biomodelos anatômicos para apoio a cirurgias com uso de impressão 3D em um hospital público brasileiro. Esse processo teve caráter interdisciplinar, envolvendo profissionais de Design, Odontologia e Fisioterapia. A avaliação foi realizada por meio de heurísticas socioambientais (diretrizes) DfS (Design for Sustainability) e possibilitou a identificação de aspectos relevantes, bem como

http://dx.doi.org/10.29183/2447-3073.MIX2023.v10.n2.91-101
ISSN: 2447-0899 (IMPRESSA) | 2447-3073 (ONLINE)

oportunidades de melhoria nos processos. Entre os resultados, destaca-se a importância de se ter um espaço específico dedicado à fabricação digital em hospitais públicos, o que agiliza o desenvolvimento de biomodelos, bem como a quantidade, diversidade e qualidade dos equipamentos de impressão 3D, que permitem a exploração de múltiplas possibilidades de processos e materiais, acelerando a inovação no ambiente hospitalar.

PALAVRAS-CHAVE
Saúde pública; cirurgia; biomodelos; impressão 3D; design de produto.

RESUMEN
Este artículo presenta, describe y evalúa, desde la perspectiva del Diseño para la Sostenibilidad (DfS), los aspectos sociales, económicos y tecnológicos del proceso de desarrollo y fabricación de biomodelos anatómicos para soporte de cirugías mediante impresión 3D en un hospital público brasileño. Este proceso tuvo un carácter interdisciplinario, involucrando a profesionales del Diseño, Odontología y Fisioterapia. La evaluación se realizó mediante heurísticas socioambientales (directrices) DfS (Diseño para la Sostenibilidad) y permitió identificar aspectos relevantes, así como oportunidades de mejora en los procesos. Entre los resultados destaca la importancia de contar con un espacio específico dedicado a la fabricación digital en los hospitales públicos, lo que agiliza el desarrollo de biomodelos, así como la cantidad, diversidad y calidad de los equipos de impresión 3D, que permiten explorar múltiples procesos y posibilidades materiales, acelerando la innovación en el entorno hospitalario.

PALABRAS CLAVE
Salud pública; cirugía; biomodelos; Impresión 3d; diseño de producto.

1. INTRODUCTION

The inclusion of new technologies in the health sector represents an important strategy in the search for improvements in health care, and this requires innovative proposals and ideas in development and processes, in addition to the design of products to increase the quality of health care practices. in Brazil (Oliveira and Rodas, 2017; Fabris, Vicentin, Sampaio, 2023). In healthcare, the use of three-dimensional technologies, also known as additive manufacturing (AM) or rapid prototyping (PR), has enabled the expansion of innovative techniques involving customization and personalization of medical products and equipment. (Matozinhos, 2017). AM, as it presents a wide field of applicability, has stood out as a promising method for prototypes and final parts (Paiva; Nogueira, 2021). The search for alternatives for health treatments has led to AM applications being incorporated into a variety of medical techniques and procedures, contributing significantly to several areas, such as oral and maxillofacial surgery, dentistry, neurosurgery, orthopedic surgery, among others (Dod; Jibhakate; Walke, 2023).

Of particular note in this study is oral and maxillofacial surgery, which has excelled with the emergence of these new technologies, which enable better diagnosis and surgical planning for craniofacial disorders. Examples include orthognathic surgery, maxillofacial reconstructions, and temporomandibular prostheses, which, through three-dimensional virtual planning, allow customizing prostheses, surgical guides, fixation plates, among others (Lima, et. al, 2023). Conventional surgical planning, although effective, requires an arduous method of manual tracing and plaster casts, in addition to a significant amount of time in its preparation and encompasses several steps that can accentuate flaws and cause inaccuracies in the outcome of surgical treatment (Resnick; Inverso; Wrzosek, 2016).

Unlike conventional surgical planning, the combination of clinical and virtual planning allows for more predictable, personalised, and precise treatment (Lima, et al, 2023). Whether with the manufacture of surgical templates (most common medical applications of 3D printing in routine practice), or in the reconstruction of bone defects, replacement of the temporomandibular joint and more recently the 3D printing of implantable biomaterials using the patient's own image data, either by computed tomography or magnetic resonance imaging (Dod; Jibhakate; Walke, 2023).

Currently, AM allows the creation of biomodels obtained from human anatomy, through the association of imaging systems with computing systems (CAD – CAM). 3D biomodels are produced from patient images acquired by resonance or computed tomography and can be manufactured in nylon using SLS 3D printing technology. The creation of biomodels or anatomical models of RP has played a very important role in Oral and Maxillofacial Surgery and Traumatology, as it allows better surgical planning in all its stages, facilitates visualization of the extent of the injury and the use of materials in the model (Sapphire , 2010), reducing the time of the surgical procedure and consequently the period of anesthesia, as well as the risk of infection, better aesthetic and functional results due to the possibility of measurement and prior conformation of the materials, contributing to the reduction of the total cost of the treatment (Peckitt , 1999; Mazzonetto et al, 2002; Meurer et al, 2003).

To enable the production of these models in public hospitals, the emergence of digital manufacturing laboratories in these institutions has been essential. These spaces, often called "healthcare fab labs," provide an environment where digital manufacturing technologies such as 3D printing, laser cutting, CNC machining and electronics are applied to the healthcare context. The Digital Manufacturing and Innovation Center (Fab.i HU) at the University Hospital of Londrina (HU UEL) is one of these digital manufacturing laboratories, which had its origins in the COVID-19 pandemic. It is part of the HU UEL structure and was opened in April 2022, with several FDM and LCD printers, 3D scanners and computers with 3D modeling software to develop projects and health products. It is in this space that the solutions presented in this article were developed, having as reference a development process in which Design assumed a fundamental role, and which will also be presented and discussed in this article.

2. THEORETICAL FRAMEWORK

• The importance of Craniomaxillofacial Reconstruction

Craniomaxillofacial deformities cause significant harm to patients, as they generally cause aesthetic sequelae that hinder social integration, compromise their quality of life and interfere with self-esteem. Furthermore, it causes serious functional sequelae, such as changes in the visual field, breathing, speech, chewing impairment and other mandibular functions (Freitas, 2006). These defects can be congenital or acquired, such as those arising from trauma, infections, bone resorption, resection of facial neoplasms, among others. In these surgical interventions, the importance of reconstructing the deformity, restoring function and facial harmony stands out, aiming for a satisfactory result (Gouveia, 2009).

Biomodels obtained by 3D printing are physical replicas of anatomical structures and allow three-dimensional visualization of the structures and their changes. They allow the advantage of evaluating the exact extent of the resection, the size and shape of the graft to be used, in addition to allowing pre-operative modelling of the plate, which considerably reduces surgical time (Gouveia, 2009). In this article, three biomodels developed at Fab.i HU will be presented and discussed, as well as an evaluation of these in terms of social and economic aspects, from the perspective of Design for Sustainability.

- **Application of 3D printing in the planning of bucocraniofacial surgeries**

3D printing has revolutionized several sectors of society, from manufacturing to medicine. In the field of healthcare and surgery, this innovative technology is playing a crucial role in enabling the creation of precise anatomical models, personalized medical devices, and even functional human organs. With continued advancements and a growing understanding of its applications, 3D printing is shaping the future of healthcare in unprecedented ways.

One of the most promising aspects of 3D printing in medicine is the ability to produce accurate and detailed anatomical models from medical imaging data such as computed tomography (CT) scans and magnetic resonance imaging (MRI) scans. The images obtained from CT scans and MRIs are stored in a format called DICOM (Digital Imaging and Communication in Medicine), containing information about bone structure and tissues, allowing digital analysis and separation of the desired structures, with which it is possible to create a piece three-dimensional model that can be used to reproduce, via 3D printing, a model that provides surgeons with a tangible physical representation of the patient and the target area of surgery (Jacobo et al, 2023).

This allows healthcare professionals to study the patient's anatomy in greater detail, plan specific surgical approaches and rehearse complex procedures before the actual operation (Matozinhos et al, 2017). Additionally, these models can be used to educate patients and their families about planned procedures, increasing understanding and acceptance of medical and dental interventions. 3D printing can also be used to simulate complex surgeries, helping surgeons develop their skills and perfect techniques before entering the operating room.

In the biomodelling of anatomical parts, 3D printing has proven to be a useful tool, whether in surgical planning, in the manufacture of personalized prostheses and in the execution of surgery, resulting in better functional and aesthetic results, as well as a reduction in risks and costs (Gouveia, 2009). Surgical methods became safer and more reliable as advances in radiology, such as computed tomography and clinical analysis methods were introduced into practice (Gouveia, 2009).

Currently, most biomodels reproduce the patient's own bone structures and are constructed from computed tomography (CT). These help the surgical team to understand the shape, relative location, orientation, and size of the anatomical structure in question (Gouveia, 2009). In some cases, biomodels are cut, sanded, and reconstructed before surgery, sometimes being sterilized, and taken to the operating room to assist on site as a visualization tool for surgical intervention (Petzold, 1999; Gouveia, 2009).

- **3D printing applied to healthcare and surgery: types of systems**

3D printing systems known as FDM (Fused Deposition Modelling) and LCD (Liquid Crystal Display) are two popular and affordable 3D printing technologies that can be used to produce these models, each with its own characteristics and applications.

Fused Deposition Modelling, or FDM, is a 3D printing process that involves depositing molten thermoplastic material, layer by layer, to build a three-dimensional object. The material is fed through a heated nozzle and deposited onto a build platform, rapidly solidifying upon deposition (Kumar and Pumera, 2021). This process uses thermoplastic materials, such as PLA (polylactic acid), ABS (acrylonitrile-butadiene-styrene) and PETG (Polyethylene Terephthalate Glycol), and its main advantage is that it is an accessible and suitable technology for reproducing bone models, allowing printing in large formats. Each material has distinct characteristics and must be chosen according to the needs of the model to be prototyped.

Liquid Crystal Display (LCD) technology is a 3D printing method that uses a photosensitive liquid resin. A thin layer of resin is exposed to ultraviolet light through a liquid crystal screen, which acts like a mask, solidifying the exposed areas (Kumar and Pumera, 2021). This process is repeated layer by layer until the object is completely formed. This technology achieves greater levels of detail and precision, but more affordable equipment has printing areas small, which makes the production of bone models difficult. However, this problem has recently started to be overcome with the arrival on the market of equipment with a larger printing volume, and at a very affordable cost.

Despite advances in recent years, 3D printing in healthcare and surgery also faces significant challenges. The safety, regulation and validation of 3D printed devices are areas that require continuous research and development, in addition to lacking explicit regulation. In short, 3D printing is playing a transformative role in healthcare and surgery, revolutionizing the way healthcare professionals approach diagnosis and treatment. With the ability to create precise anatomical models, this technology is opening doors to a future where healthcare is more effective, personalized, and accessible. Although challenges remain, the potential positive impact of 3D printing on medicine is undeniable.

• Digital manufacturing labs in hospitals: The Fab.i HU

Fab.i HU is a laboratory linked to the research project No. 12565/2020 and was institutionalized by HU UEL in April 2021. HU UEL is a Supplementary Body of the State University of Londrina (UEL), being recognized by the Ministry of Education and Ministry of Health, under the terms of Interministerial Ordinance MEC/MS No. 1,213 of 05/30/2014, as well as Health License (verification code No. 8264312). HU UEL is the second largest public hospital in Paraná, being considered a strategic and traditional reference centre in medium and high complexity, 100% SUS (Unified Health System). It is worth mentioning that HU UEL was one of the references and support in the Covid_19 epidemic in the State of Paraná.

Since its institutionalization, Fab.i HU has already developed several solutions for the areas of Paediatrics, Pulmonology, Burn Treatment Centre (CTQ), Dentistry/Oral and Maxillofacial Surgery, and is now seeking to expand its reach to other areas of health from hospital. Having the laboratory integrated into the hospital structure has several advantages, among which we can highlight:

- Medical customization: allows the creation of personalized medical devices, prosthetics and implants adapted to the specific needs of patients. This can result in more effective treatments and a better quality of life.
- Cost savings: On-site manufacturing of medical devices reduces costs compared to purchasing commercial devices. Additionally, customization can eliminate the need for subsequent adjustments, saving time and resources.
- Rapid prototyping: Rapid prototyping allows healthcare professionals to test ideas and designs before larger-scale production, accelerating medical innovation.
- Reduction in surgery/hospitalization time: with the ability to produce models so that the medical team can practice the surgical procedure or even carry out measurements to produce implants and prostheses, the patient's time in the surgical centre is reduced, generating savings, and promoting shorter anaesthesia time. This means the patient spends less time in the hospital, as it allows for a faster recovery.

In addition to these advantages, the fact that the laboratory is linked to the Hospital allows for multidisciplinary collaboration, generating more efficient and comprehensive solutions, in addition to allowing efficient management of resources, including financing, space and personnel. Compared to traditional fab labs, as they have a specific medical context, at Fab.i HU the R&D team ends up having a deeper understanding of medical needs, allowing the creation of more targeted solutions. Proximity to doctors and patients makes it easier to test and implement innovative devices and solutions. Additionally, the presence of healthcare professionals can guide the design of solutions that meet medical safety and effectiveness standards.

But there are also disadvantages, such as regulatory complexity. Medical devices are subject to strict regulations and healthcare laboratories must ensure compliance with standards and approvals. Furthermore, they end up having limited resources, as they depend on bidding and must follow bureaucratic procedures that often end up making certain applications unfeasible. In summary, digital manufacturing laboratories in hospitals represent an important milestone in the convergence between healthcare and technology. These spaces offer a platform for personalized medical innovation, although they present regulatory and resource challenges. Compared to traditional fab labs, healthcare labs stand out for their medical specialization and clinical integration.

3. METHODOLOGY

In addition to a bibliographical review, the method used in this study is the case report of the development of three artifacts (jaw biomodel for orthognathic surgery, skull biomodel for craniomaxillofacial reconstruction surgery, and skull biomodel for bone dysplasia correction surgery), from which a qualitative assessment was carried out based on social and economic heuristics, based on Santos, et al (2019).

4. RESULTS

Below are three biomodels that were prototyped by Fab.i HU in response to the request of the hospital's Oral and Maxillofacial surgical team: 1) biomodel to support orthognathic surgery (jaw printed in green PLA); 2) biomodel to support craniomaxillofacial reconstruction surgery (skull printed in crystal liquid resin) and 3) biomodel to support bone dysplasia correction surgery (jaw printed in crystal PETG).

- **Biomodel 1: Orthognathic surgery**

Orthognathic surgery is a procedure used to correct facial asymmetry to correct and reposition the jaw bones, and, consequently, the dental positioning of patients who have different degrees of asymmetry in the region (Modonesi et.al, 2017). In this case, the 3D model of the mandible in stl format was opened in the Rhinoceros 7 software for verification together with a professional from the surgical team, and then imported into the Ultimaker Cura software to generate a gcode file, which was then sent to be printed on an Ender 5 Plus 3D printer, in 1.75mm PLA plastic filament, in green, using a 0.4mm printing nozzle. The printing took approximately 6 hours, and the model proved to be suitable for the intended purpose of surgical planning, allowing it to be machined with micro-grinding equipment (Figures 1a and 1b).

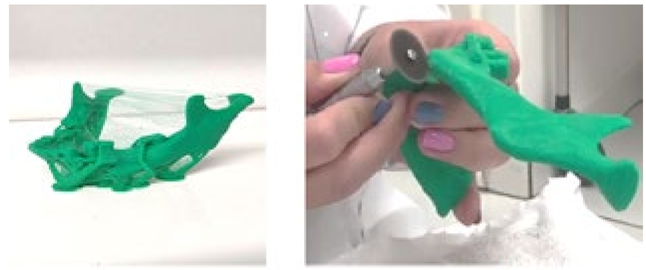
(a) (b)

Figure 1: Mandible printed in PLA with the impression supports (a) and being machined by a professional from the surgical team in the surgery planning stage (b).
Source: prepared by the authors.

- **Biomodel 2: Craniomaxillofacial deformity**

To optimize the results of craniomaxillofacial reconstructions, careful planning is necessary with excellent anamnesis, pre-operative preparation, imaging tests, creation of biomodels, selection of the biomaterial indicated for reconstruction and, above all, choice of the appropriate surgical technique. Depending on the complexity of the cases, a multidisciplinary approach is required. For this application, the 3D model in stl format provided by the surgical team was also reviewed in the Rhinoceros 7 software together with a professional from the surgical team. However, the generation of the print file was done using the Halot Box software, specific to the Halot One printer, as the laboratory team wanted to experiment with the use of resin printing to evaluate the viability of this technology in surgical biomodels. A 3D model of a male skull was printed, which had to be produced in parts due to the small size of the equipment's printing area. After removing the part, the printing supports and washing to remove excess resin, the parts were subsequently joined using resin applied with a brush, followed by curing by ultraviolet rays in equipment suitable for this purpose.


(a) (b)

Figure 2: Skull printed in resin on an LCD printer, in side (a) and front (b) views.
Source: prepared by the authors.

The process proved to be viable, although laborious, as the assembly was done by hand. However, this difficulty can be overcome with the use of larger volume resin printers, currently available on the market and at a viable cost (around R$5,000). The model presented a high quality of finish (Figures 2a and 2b), but also excessive rigidity for the need for machining by the surgical team. It is worth noting that the laboratory has six Halot One equipment, two of which are intended for printing in rigid resin like the one used in this biomodel, and the others for testing with other types of resin, such as flexible or pigmented).

- **Biomodel 3: Bone dysplasia**

Bone dysplasia is described as a benign disorder of bone development, characterized by the replacement of normal bone by an excessive proliferation of fibrous connective tissue. A piece obtained from the CT image of a patient who had bone dysplasia was manufactured for the surgical procedure of osteoplasty in the maxillary region. As with previous biomodels, this part was printed from a stl file provided by the surgical team, using Rhinoceros 7 software for evaluation and Ultimaker Cura to generate a gcode file for 3D printing.

(a) (b)

Figure 3: Skull printed in PETG, with printing supports (a) and front (b).
Source: prepared by the authors.

This piece was printed on an Ender 5 Plus printer but, unlike biomodel 1, 1.75mm PETG filament was used with a 1mm printing nozzle. Therefore, biomodels 1 and 3 were printed on two different FDM printers, which was possible since the laboratory has four pieces of equipment of this type. The objective of using the 1mm nozzle is to reduce printing time on parts that do not require very high precision, as was the case with biomodel 3.

- **Development and manufacturing process**

The creation of the three biomodels followed the same basic work process, but with some specificities for each of the pieces, as follows:

- Receipt of the 3D file of the object to be printed in stl format, delivered by a professional from the surgical team.
- Conference of the 3D model together with the surgical team professional.
- Discussion with the requesting professional about the attributes that the material should fulfil to meet the needs (surface quality, malleability, mechanical resistance, hardness level, ease of cutting, machining and pen markings, absence of post-printing lint), as well as the deadline for delivery of the part.
- Definition of printing material, layer resolution, fill level, use of supports and other printing parameters.
- 3D printing of the biomodel.
- Removal of printing supports, cleaning, curing (resin printing) and finishing.
- Delivery of the biomodel to the surgical team.

Next, the development of these biomodels will be discussed from aspects of social and economic sustainability, from the perspective of Design for Sustainability, and based on the heuristics described by Santos, et al (2019).

5. ANALYSIS OF RESULTS

- **Aspects of social sustainability: benefits for the hospital's internal and external public**

The evaluation of the social aspects of the processes described above was carried out considering the following heuristics, as proposed by Santos et al (2019): improve working and employment conditions; favour the inclusion of everyone; improve social cohesion; value local resources and skills; promote education in sustainability, and instrumentalize responsible consumption. Of these, three were considered relevant to this study, and are discussed below.

Improve working and employment conditions

In this case, we can see an improvement in working conditions for surgical professionals, who, with the use of biomodels, begin to perform faster, safer, and therefore less tiring and stressful surgeries, with direct impacts on the well-being of patients. surgical patients, who, thanks to the reduction in surgery time, also have their risk level (contamination, complications) and stress reduced. In this aspect, surgical team professionals reported, for example, reductions in surgery time from more than five hours to less than two hours, a significant gain thanks to the use of biomodels for prior surgery planning.

Encourage the inclusion of everyone

The use of surgical biomodels and the reduction in surgery time also imply the possibility of performing new surgeries, expanding the reach of the public health service to more patients. Considering that a large part of the public that seeks care at HU UEL is low-income, there is an obvious social benefit in favouring the inclusion of these people in care, which is provided entirely via SUS. The incorporation of 3D printing in this case presents benefits that can be concretely perceived by the population.

Valuing local resources and skills

The digital manufacturing of biomodels located within the hospital can be considered an example of distributed production, in which the production and distribution of goods is carried out locally and decentralized, without direct dependence on a few producers who are far from consumers. Although the equipment and inputs originate from suppliers far from the hospital, once the 3D printing infrastructure is installed, the hospital gains greater autonomy in the development, production, testing and delivery of solutions. Therefore, we start using a local resource (in this case the 3D printing laboratory) and local skills (in this case the laboratory team, made up of researchers, professors, and students from the university to which the hospital belongs).

- **Aspects of economic sustainability: benefits for the hospital and the SUS**

The economic heuristics proposed by Santos, et al (2019) refer to: strengthening and valuing local resources; respect and value local culture; promote and local economy; promote network organizations; value the reintegration of waste and promote education for a sustainable economy. Of these, those that we consider most significant in the process of producing surgical biomodels are discussed below.

Strengthening and valuing local resources

In addition to the social implications, prioritizing the choice of local resources (material, technical, financial, human) over those of external origin is also an economic heuristic, as it can lead to a gain in competitive advantage. In the case of a public hospital, the main advantage of having the 3D printing laboratory as a local resource is the reduction in costs resulting from the reduction in surgery time, with savings in both team working hours and costs resulting from the reduction of risks, already mentioned previously.

Promotion of the local economy

Once installed, to produce biomodels, the laboratory starts to consume different types of inputs (filaments, glues, spare parts), as well as maintenance and repair services that can be purchased from local companies, which helps to strengthen chains of value in the city itself, generating work and local income. Furthermore, the technical-scientific knowledge generated in the laboratory and disseminated through articles, reports, lectures, courses, and other forms of dissemination enables other actors external to the hospital to also create new business models, thus encouraging locally based entrepreneurship, which is also favoured by the existence of an innovation agency at the university to which the hospital is linked.

Promotion of networked organizations

The development of biomodels involves the interaction of professionals from different areas (design, physiotherapy, dentistry, medicine, surgery), in an interdisciplinary way. This interaction can occur both within the hospital and outside it, with professionals from other institutions, both public and private, which enables the exchange of information and knowledge that leads to the creation of a virtuous circle of learning with consequences for the entire health system. In this sense, it is important that the hospital offers a good information technology structure, with a quality intranet and internet and good work equipment. In a broader and more systemic way, the creation and strengthening of these network organizations also allows the health system to increase its resilience to respond with more agility, assertiveness, and efficiency to future critical situations, such as the pandemic that occurred in recent years.

Technological aspects: challenges and benefits

The main technological challenges to produce biomodels are also common to other types of artifacts developed by Fab.i HU, the main ones being the following:

- Constant need for technological updating, both in equipment and materials and processes, with a risk of rapid obsolescence in both.
- Infrastructure maintenance, mainly 3D printing equipment.

- Constant need to search for sources of financing, both for the infrastructure and for the maintenance of qualified technical personnel to operate the equipment.
- Growing demand for products and services by the hospital, requiring expansion of the centre's service capacity.
- Dependence on labour provided by the university itself, especially research professors and research fellows with short-term contracts that need to be renewed annually. In the case of new fellows, training is required to enable them to use the laboratory's infrastructure and internal processes.

These challenges point to the need to develop and execute an innovation policy and strategy appropriate for the laboratory, which must necessarily include technological, economic-financial, informational, intellectual, social, and environmental capital dimensions.

Environmental aspects: a future challenge

The environmental aspects involved in the production of biomodels for surgical use are one of the topics to be investigated in the future by the team, which should be done considering both the search for greater environmental efficiency (eco-efficiency) in the life cycle of biomodels, and the dematerialization in production and consumption (focusing on the final benefit rather than the product itself). In this sense, some aspects have already been identified by the team, including energy consumption, reduction in material waste and the possibility of reuse and/or recycling, which will be investigated in a future article.

6. FINAL CONSIDERATIONS

In this work it was possible to understand the relevance of using 3D printing in the production of biomodels for surgical use, as an important instrument for the prior planning of surgeries, as well as the importance of having a laboratory dedicated to this activity within a public hospital, equipped with quality equipment and in good quantity. The importance of adopting an interdisciplinary process between different areas was also highlighted, including Design, Physiotherapy, Dentistry and Medicine, especially for professionals who work in a surgical environment. The social and economic benefits were evaluated using Design for Sustainability heuristics, which allowed a more specific reading of these, highlighting relevant aspects, as well as opportunities for improving processes. The environmental dimension will be explored by the Fab.i HU research team in future studies.

REFERENCES

FABRIS LUIZ, S.M; VICENTIN, J.A, SAMPAIO, C.P. **ENSUS 2023 – XI Encontro de Sustentabilidade em Projeto** – UFSC – Florianópolis – 05 a 07 de Junho de 2023.

FREITAS, R. Tratado de Cirurgia Bucomaxilofacial. São Paulo, Editora Santos, 2006.

GAURAV, D; JIBHAKATE, R; PRAMOD WALKE, A. Review on 3D printing maxillofacial surgery: Present work and future prospects, **Materials Today: Proceedings**, 2023.

GOUVEIA, M.F. Aplicação da prototipagem rápida no planejamento de cirurgias craniofaciais. **Tese de doutorado apresentada à comissão de Pós-graduação da Faculdade de Engenharia Mecânica, como requisito para a obtenção do título de Doutor em Engenharia Mecânica**. Campinas, SP, 2009.

JACOBO, O.M., et al. Three-dimensional printing modeling: application in maxillofacial and hand fractures and resident training. **Eur J Plast Surg** 41, 137–146, 2023. Disponível em: https://doi.org/10.1007/s00238-017-1373-0. Acesso em: 30 ago 2023.

KUMAR, K. P. A.; PUMERA, M. 3D-Printing to Mitigate COVID-19 Pandemic. Advanced Functional Materials, v. 31, n. 22, p. 2100450, 2021. Disponível em: https://onlinelibrary.wiley.com/doi/10.1002/adfm.202100450. Acesso em: 30 ago 2023.

LIMA, F.G.G. P., et al. Planejamento Virtual e novas tecnologias em cirurgia buco-maxilo-facial. **Repositório.ufu.br**, 2023.

MATOZINHOS, Isabela Penido et al. Impressão 3D: Inovações no campo da medicina. **Revista Interdisciplinar Ciências Médicas**-mg, Mg, p.143-162, 2017. Disponível em: http://200.169.1.56/ojs/index.php/ricm/article/view/14/11. Acesso em: 30 ago 2023.

MAZZONETTO, R. et al. Uso de biomodelos esteriolitográficos em cirurgia bucomaxilofacial. **R. Assoc. Paul. Cir.**

Dent., São Paulo, v.56, n.2, mar./abr. 2002.

MEURER, E. et al. Os biomodelos de prototipagem rápida em cirurgia e traumatologia bucomaxilofacial. **R. Bras. Cir. Periodontia**, Curitiba, v.1, n.3, p.172-180, 2003.

MODONESI, et. Al. Cirurgia Ortognática: Assimetria Facial e a Limitação do Planejamento Manual: Correção com Planejamento Virtual (3D): Relato de caso. **FOL** - Faculdade de Odontologia de Lins/Unimep, 27(2) 63-73, jul.-dez. 2017.

PAIVA, T. N.; NOGUEIRA, C. C. Estudo comparativo das principais tecnologias de impressão 3D no Brasil. **Jnt-Facit Business and Technology Journal**, v. 1, p. 179–190, 2021.

PECKITT, N. S. et al., The cost of treatment. Disponível em: http://www.maxfac.com/cost1.htm. Acesso em: 29 ago. 2023.

PETZOLD, R.; Zeilhofer, H. F.; Kalender, W. A. "Rapid prototyping in medicine – basics and applications. Computerized Medical Imaging and Graphics", Tarrytown, NY., v. 23, n.5, p.277-284, Sep./Oct. 1999.

RESNICK, C. M.; INVERSO, G.; WRZOSEK, M. Is There a Difference in Cost Between Standard and Virtual Surgical Planning for Orthognathic Surgery? **Journal of Oral and Maxillofacial Surgery**, v. 74, n. 9, p. 1827–1833, 2016. Disponível em: http://dx.doi.org/10.1016/j.joms.2016.03.035. Acesso em: 29 ago 2023.

SAFIRA, L.C; MACIEL, A.S; SOUTO-MAIOR,J.C.C; AZEVEDO,R.A; CAVALCANTE,W.C; FRANCISCHONE,C.E; SARMENTO, V. A. Aplicação dos biomodelos de prototipagem rápida na Odontologia, confeccionados pela técnica da impressão tridimensional. **R. Ci. méd. biol**. 2010; 9(3):240-246.

SANTOS, A. et al. Design para sustentabilidade: dimensão econômica / Organizado por Aguinaldo dos Santos - Curitiba, PR: Insight, 2019.

SANTOS, A. et al. Design para a sustentabilidade: dimensão social / Aguinaldo dos Santos...[et al.] - Curitiba, PR : Insight, 2019.

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HOW TO CITE THIS ARTICLE

SAMPAIO, Claudio Pereira de; FABRIS, Sonia Maria; VINCENTIN; José Antonio; STABILE, Glaykon Alex Vitti; STABILE, Cecília Luiz Pereira Stabile. MIX Sustentável, v. 10, n. 2, p. 91-101, 2024. ISSN 2447-3073. Disponível em: <http://www.nexos.ufsc.br/index.php/mixsustentavel>. Acesso em: _/_/_.doi: <https://doi.org/10.29183/2447-3073.MIX2023.v10.n2.91-101>.

SUBMETIDO EM: 15/01/2024
ACEITO EM: 20/12/2024
PUBLICADO EM: 02/05/2024
EDITORES RESPONSÁVEIS: Lisiane Ilha Librelotto e Paulo Cesar Machado Ferroli

Record of authorship contribution:
CRediT Taxonomy (http://credit.niso.org/)

CPS: Conceptualization, data curation, formal analysis, funding acquisition, Investigation, methodology, Project administration, supervision, validation, visualization, writing – original draft and writing – review & editing.

SMF: Conceptualization, data curation, formal analysis, funding acquisition, Investigation, methodology, Project administration, supervision, validation, writing – original draft and writing – review & editing.

JAV: Data curation, formal analysis, Investigation, methodology, validation, visualization, writing – original draft and writing – review & editing.

GAVS: Investigation, methodology, supervision, validation, visualization, writing – original draft and writing – review & editing.

CLPS: Investigation, methodology, supervision, validation, visualization, writing – original draft and writing – review & editing.

Conflict declaration: nothing has been declared.