https://doi.org/10.4322/rae.v17n2.e202309.en

XXIII CONGRESSO BRASILEIRO DE ERGONOMIA
XVI FÓRUM DE CERTIFICAÇÃO DO ERGONOMISTA BRASILEIRO
XVII FÓRUM DOS GRUPOS TÉCNICOS DA ABERGO

DIGITAL MANUFACTURE FOR EDUCATION IN ERGONOMICS AND UNIVERSAL DESIGN

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Summary

The teaching of Ergonomics and Universal Design in Architecture and Engineering courses requires a theoretical and practical approach through methodologies that use new technologies available on the market. Specifically addressing Anthropometry, the use of digital fabrication and 3D printing allows students to develop experimentation and problem-solving skills. The objective of this study is to present the process of developing teaching material for teaching Ergonomics and Universal Design (UD), through digital manufacturing and 3D printing, in a way that offers support and contributes to the understanding of the topics. The development of a scale prototype involved tests and studies of improvements for the sizing of a model that uses anthropometric percentiles. Through scale models in the desired percentiles (5%, 50% and 95%) it is possible to demonstrate in the classroom the relationship between the environment and its user with the impression of elements of our daily lives such as furniture, ramps, stairs and fenestrations . It is understood that the use of digital manufacturing in teaching Ergonomics and Universal Design meets new methodologies for the teaching-learning process, encouraging students to study them.

Keywords: Ergonomics; Universal Design; Digital manufacturing; Anthropometry.

1. Introduction

The study of user-centered spaces involves both knowledge of human physical dimensions (standing height, sitting height, among others) and working dimensions, which address the dynamics of the body in space. Additionally, factors such as age and physical limitations demonstrate that it is not appropriate to use dimensions established by average values in the project, disregarding the real needs of those who use the space (PANERO, ZELNIK; 2008). The relationship between the user and the built space also includes cultural elements and individual values of the perception of space, which affect people's quality of life (HERZBERGER, 1999; HALL, 2005). Areas of knowledge such as Ergonomics and Universal Design (UD) provide methods of understanding user needs and, therefore, can collaborate with user-centered design processes (DORNELES; BINS ELY, 2018).

For Iida and Buarque (2016), Ergonomics consists of the application of concepts of anatomy, physiology and psychology to solve problems arising in the relationship between man and the environment. Moraes & Mont'Alvão (2003) consider Ergonomics beyond the relationship between man and tool, including the interactions and communications that take place in the environment. In the case of Universal Design, MACE et al. (1996) define it as the design of products, buildings and open spaces that meet the different spatial needs and different limitations of users. However, UD is different from accessibility, in that accessibility promotes a design that is accessible to specific individuals or groups of individuals with limitations (ORMEROD; NEWTON, 2011).

The themes are gaining more and more space within the training of new professionals. DU, for example, became mandatory content for Architecture and Engineering courses through resolution No. 1, dated March 26, 2021 (CNE, 2021). Therefore, different perspectives related to the teaching-learning process and methodological strategies are fundamental to meet the resolution (MALULI; LOPES; VERGARA, 2022; NETO; ANDRADE; RIBEIRO, 2022; SIMONETTO; MEDEIROS, 2022). The theoretical and practical approach, both in Ergonomics and DU, through teaching dynamics that relate concepts to experimentation is fundamental for students to develop problem-solving skills (BRAATZ et al., 2017). The interdisciplinarity of Engineering with Architecture allows the relationship of human-technology interaction systems in the design of artifacts (VERGARA, 2005), which provide the discussion of concepts through the application of usability tests (GONÇALVES, 2017). Additionally, the use of new technologies in the production of artifacts makes the themes more attractive to students while preparing students for the market.

New forms of production associated with digital technology work as great allies in project innovation, manufacturing and construction. Recent means of production, which include rapid prototyping and digital manufacturing, incorporate the manufacture of artifacts with new perspectives for advancement and innovation in learning and knowledge assimilation

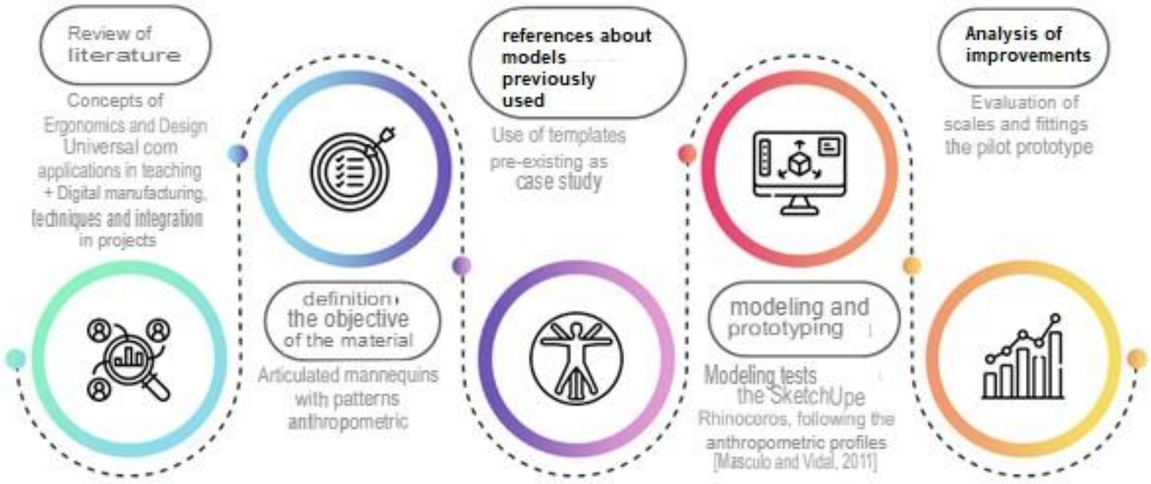
(SCHEEREN, 2021). Therefore, the objective of this article is to present the process of developing didactic material for teaching in Ergonomics and Universal Design, through digital manufacturing and 3D printing, in a way that offers support as teaching material and contributes to the understanding of the topics.

2. Development

The study is characterized as quantitative-qualitative in terms of its approach, focusing on explaining the dynamics that involve the user's relationship with the space. As for its nature, it is characterized as applied research, as it is aimed at solving specific problems. Regarding objectives, the research is classified as exploratory, as it seeks information and the construction of hypotheses (GERHARDT; SILVEIRA, 2009).

Figure 1 illustrates the development stages of the present study: Stage 1. literature review; Step 2. definition of the objective of the material; Step 3. references to previously used models; Step 4. modeling and prototyping; and Step 5. analysis of improvements. In order to bring the researcher closer to the content already published on the study themes (MARCONI; LAKATOS, 2003), Stage 1 of this study consisted of collecting data involving research in journals and scientific events about the concepts of Ergonomics and UD and their teaching in Architecture and Engineering courses. In addition, the literature review on the use of digital fabrication, manufacturing techniques and the integration of prototyping in the design stage as well as its impacts on experimentation, solution of design problems and the development of students as reflective professionals.

Figure 1 – Research development stages



Source: Authors, 2023

Due to the breadth of study themes, after the bibliographical review it was realized that anthropometry brings Architecture and Engineering courses closer together by involving procedures and techniques for understanding the measurements and shapes of the human body and its relationship with the environment (GONÇALVES, 2017). In the project conception, understanding these measurements is a fundamental part of defining the dynamics of use and sizing of spaces. It was noted, as part of Stage 2, that articulated mannequins portray, generally on reduced scales, human measurements and proportions and are tools that, together with constructive elements, can be used in teaching Ergonomics and DU. Therefore, this was the theme chosen for the development of the following stages.

To better understand the links between anthropometric models and the teaching of Ergonomics and UD, Stage 3 aimed to search for previously used models, inside and outside the scientific environment through case studies, considering physical characteristics and identifying applied guidelines.

After the literature review and theoretical formulation of the anthropometric study related to digital manufacturing, modeling tests began (Stage 4) based on the anthropometric percentiles available in the book by Másculo and Vidal (2011). Due to the authors' prior knowledge, it was decided to initially use the educational version of the SketchUp software.

During the modeling, it was realized the need to look for other software that would enable more complex modeling, given that SketchUp tools are limited for anatomical modeling.

The program chosen for the study modeling was Rhinoceros, using the free version for testing, which met the previously perceived demand. The production of pilot prototypes was printed in PLA filament (Polylactic Acid Biopolymer) on a Creality printer, model CR-10S Pro, in the spaces of the Digital Fabrication Laboratory of the Technology Center of the Federal University of Santa Maria (UFSM) - Fábrica CT .

Finally, Stage 5 of analyzing the printed prototypes, and the entire development process, aiming for improvements was carried out.

3. Results

Based on the aforementioned methods, strategically defined for the purpose of this study, the evidence obtained for the analysis is presented. The next sections discuss the results found for each stage of the study development.

3.1. Literature review on digital manufacturing and teaching in Ergonomics and DU

Digital manufacturing enables the mass production of different personalized elements, known as mass customization (CELANI; PUPO, 2008). This process is associated with digital design and the virtual manipulation of shapes, so that the procedures are controlled by a computer and codified for subsequent production (BARBOSA NETO, 2013). Considering industrial-scale production in the construction sector, digital manufacturing is associated with the final production of formwork or final parts of buildings or other elements that make up the construction. In the case of rapid prototyping, it is associated with the manufacture and materialization of prototypes that will be used for analysis and verification of virtual models (PUPO, 2009).

Rapid prototyping is further divided by the type of manufacturing: additive, subtractive or formative. Additive manufacturing is defined by the overlapping of layers of material, whether solid or liquid, using equipment such as a 3D printer. Subtractive manufacturing refers to the grinding of a material using equipment such as milling, laser cutting and water jetting. Formative manufacturing is based on a mold on which the material deforms and adapts (PUPO, 2009; BARBOSA NETO, 2013; FACCA et al., 2022).

In Architecture and Engineering courses, the use of rapid prototyping helps the design process as a creation and application tool, uniting the digital and physical worlds. The experimentation provided by modeling and prototyping stimulates students' curiosity, while generating an environment for sharing knowledge (FACCA et al., 2022). Project problem solving enhances students' different capabilities through data research, use of innovation and decision making (FERREIRA; FREITAS-GUTIERRES, 2022). Furthermore, they provide their development as reflective professionals, reflecting in action and on action (SCHÖN, 2009).

3.2. Definition of the objective of the material: Anthropometry

In the literature, studies are found that use modeling and additive manufacturing to manufacture prosthetics and orthoses, medical products, furniture, everyday products and tactile maps in different disciplines and themes (BATISTELLO et al., 2015; SOUZA et al. , 2017; ANDRADE; AGUIAR, 2018; SOUSA ET AL., 2019; KERMAVNAR; SHANNON; O'SULLIVAN, 2021). However, it was noted that there are few studies with anthropometric models for teaching Ergonomics and UD. The models available on the market, such as shape mannequins, represent the articulation of movements and proportionality between dimensions of the human body. Models created based on measurement standards, according to anthropometric percentiles, are difficult to find. In addition, elements of our daily lives such as doors, stairs and furniture, which are basic teaching examples for Ergonomics and DU, are not associated as physical models that can be used in practical teaching.

It is noteworthy that anthropometry must be understood as an inclusion tool, since among the principles of DU (DORNELES et al., 2013) such as equitable use, low physical effort and space for approach and use depend on adequate sizing for different users who use a space and/or furniture. The elimination of physical barriers depends on the assimilation of anthropometry and the user-environment relationship through practical applications that demonstrate to students the importance of the topic.

3.3 References on previously used models

Scientific research on models created from 3D scanning of real bodies, digitized for later printing on mannequins, seeks to assist in the manufacture of clothes, shoes and accessories in accordance with the measurements of the respective populations under study (SPAHIU et al., 2016; OH ; SUH, 2021; COPILUSI et al., 2023). The Mandesso Design office, led by industrial engineer Manu Alvarez, developed 29 digital human models covering the 1%, 50% and 95% percentiles at ages between a 2-month-old baby and adults. Unfortunately, it is not possible to access data from Alvarez's study (MANDESSO, 2023). Other models available digitally, without a scientific nature and free of charge, can be found on specific 3D printing websites such as Thingiverse and Cults.

Despite the models and studies available, there are still few resources aimed at teaching ergonomics and DU, especially those that do not require high investment resources. Therefore, the development of teaching material that can be used in various courses and higher education institutions is essential for the dissemination of knowledge.

3.4. Modeling and prototyping

For the initial development of the study model, drawing by overlaying images in the Sketchup software was tested. Based on the fit of the wooden mannequins available on the market, it was verified that the original fit made by nails and springs was difficult to access for manufacturing due to the scale of the print. Although the tests were carried out on scales of 1:20 and 1:10 (Figure 2), it would hardly be possible to produce the parts necessary for fitting, making it a manual and artisanal production, which was not in line with the objective of the study. Using a bench drill and making the springs would make the process long and difficult to replicate.

Figure 2 – Printing and drilling tests based on wooden dummies

Source: Authors, 2023

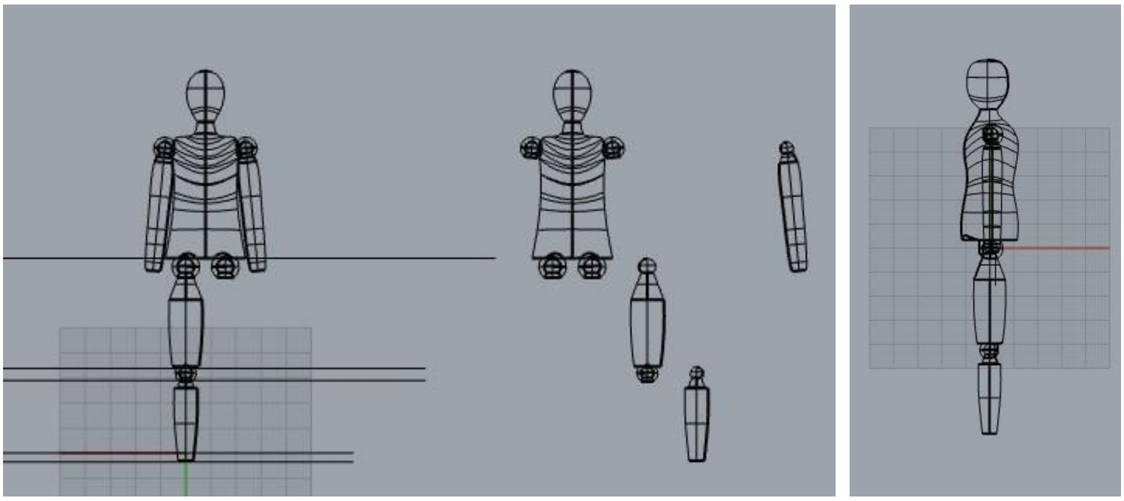
Therefore, in a second phase, it was decided to use an articulated model available in the Thingiverse website library (Figure 3). Despite not having ergonomic measurements, the model has a fitting system that, after printing, worked properly for the study. However, the model has rights of use and did not meet desired positions such as fixing ranges and standing/sitting positions, having joints beyond those necessary for the purpose of the study.

Figure 3 – Printing of model available on the internet

Source: Makermachine, 2023

In the third phase, based on the fitting system and the review of the desired positions, the authors began developing their own model in the Rhinoceros software (Figure 4). The software, aimed at digital modeling, allows different shapes to be created and modified. Its resources support the interaction and associations of different objects, as well as the development of a parametric design through the Grasshopper plugin. Its main disadvantage is the condition of having a paid license, even for students. Therefore, it was used in the free trial version to check whether it fits the proposed study.

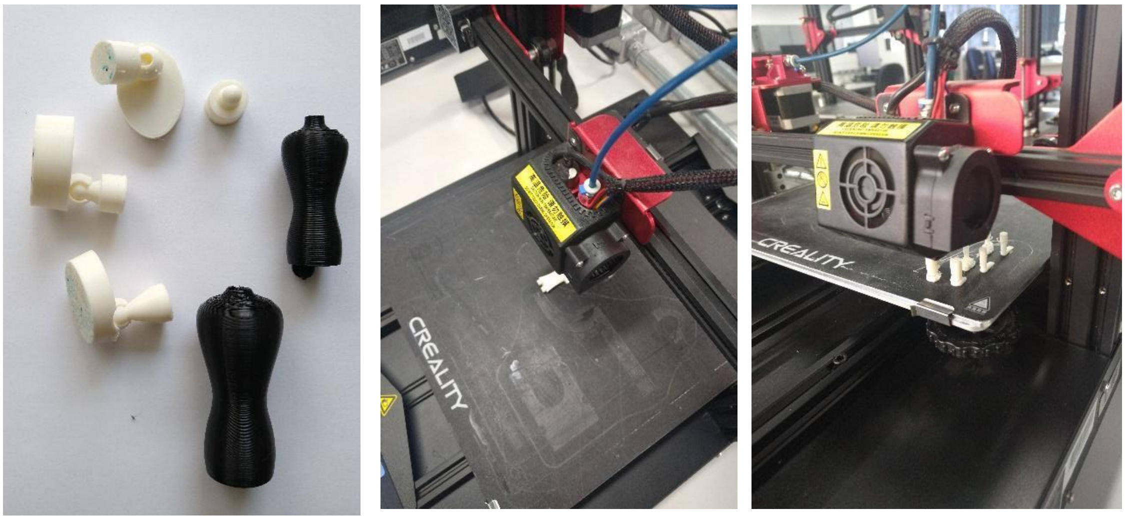
Figure 4 – Prototype modeling



Source: Authors, 2023

Several tests were necessary on parts of the pieces for the fittings to work, so that minimum movements were possible, such as: extension of arm reach, standing position, sitting position (Figure 5). The lack of movement stabilization, as well as the breakage of parts during movement, were the biggest challenges for the modeling to work in print. The fine adjustment in the size of each joint with its respective fitting, as well as its proportionality for movements, were ensured after constant printing tests. Likewise, the configuration of the 3D printer software, Ultimaker Cura, allows you to change densities, number of layers and thickness sizing to reinforce the part and prevent it from breaking. The aim is also to explore the compositional balance of body shapes with these fittings, making the whole more harmonious.

Figure 5 – Test printing of prototype fittings



Source: Authors, 2023

3.5. Improvement analysis

The pilot prototype was printed on a 1:20 and 1:10 scale (Figure 6) with the anthropomorphic dimensions of the 50% percentile (VIDAL, 2000) for final verification of the modeled fits. It was found that on a higher scale the model works more adequately for the proposed study, as well as the reinforcement carried out on the spherical structures to prevent breakage during use. Fine tuning brings greater stability and durability to the final model. Based on the adjustments, it is possible to model the other percentiles (5% and 95%) and create models that are similar in size to the population's daily lives.

Figure 6 – Prototype and simulation doors.

Source: Authors, 2023

In general, it should be considered that it is necessary to develop skills in using the Rhinoceros software to speed up the modeling process and minimize errors. Correct adjustment of the model requires knowledge and experience to identify problems such as incorrect closure and intersection of objects, proportionality of shapes and sizing between fitting parts. Additionally, the configuration of the Ultimaker Cura printing software that generates the supports, layer thickness, type of adhesion of the object to the table and filling added to the type of filament used, which needs to meet the needs of the prototype.

4. Conclusions

The prototype developed for this study, through digital manufacturing and 3D printing, with the aim of being used as teaching material for teaching Ergonomics and Universal Design, represents the practical application of anthropometric dimensions and percentiles. The methods used to create the model and the 3D printing tests required the investigation of the best means for designing a model that could meet the perspectives of an innovative material. Through scale models in the desired percentiles (5%, 50% and 95%) it is possible to demonstrate in the classroom the relationship between the environment and its user with the impression of elements of our daily lives such as furniture, ramps, stairs and fenestrations .

However, the learning curve required to understand different modeling and printing software is a limitation. Specifically for printing, there are also variations depending on the type of 3D printer, which can use generic software (such as the Ultimaker Cura) or proprietary software. The relationship between the modeled object and the printed object must also be taken into account, taking care with the scales that each software uses and the possible lag between them.

Encouraging students to participate in the creation of elements and reflect on the interaction between different human bodies, their dynamics and their scope is fundamental for active teaching and to prepare them for the professional market. The use of the model in Architecture and Urbanism courses can occur in design disciplines, while in Engineering courses it can occur in Ergonomics disciplines, since anthropometry must be understood by the diversity of measurements and the interaction of the human body with space.

Finally, the practical application and knowledge of different types of users and how they relate to the environment makes it possible to raise students' awareness of the barriers that are found in our daily lives and minimize the barriers that do not guarantee inclusion as a whole.

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