Original scientific paper

Customized helmet design using computational and physical prototyping design principles

ABSTRACT

Bicycle helmets are designed to protect the user in case of a fall or collision. The effectiveness of a helmet depends on many factors, one of which is its correct fit on the user's head. The presented paper aims to develop an application that can generate personalized helmet designs based on user-provided data. After receiving the user's data, the design process is automatically carried out via a computer-based algorithm. The data provided includes two photos, capturing both the front and side views of the user's head. Using these images, the algorithm analyzes the curvature, proportions, and size of the head to create curves that closely align with the user's head shape. This information is then used to design a helmet comprising of two main components: the outer shell and the inner lining. The outcomes of this study were effectively assessed through two methods. The initial evaluation involved digital analysis using 3D scanning technology to compare the head curvatures between the algorithm and the scanned model. The second evaluation utilized 3D printing technology. Using appropriate materials, the helmet was fabricated while its geometry was applied evenly to the user's head.

KEY WORDS
helmet design, safety design, computational design, product design, wearable devices, algorithmic design, visual programming, 3D printing

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Introduction

The process of helmet design focuses on creating a product that prioritizes user safety, as well as comfort and aesthetics. Helmets are designed to be lightweight, durable, and visually appealing. More specifically, end-users seek out the perfect helmet for themselves based on these features, turning the chosen product into a personal accessory. The most conventional materials used to make a helmet are expanded polystyrene (EPS) foam. This material can greatly and effectively reduce an impact. In recent years, the design of helmets has also included inspiration elements from nature according to biomimicking principles. Using novel technologies, helmet geometries with complex structures and composite materials are now being designed and produced (Leng, Ruan & Tse, 2022). Computational design is a design methodology based on Computer Aided Design (CAD) system programming.

Based on computational design, 2D (two-dimensional) and 3D (three-dimensional) geometries can be modelled using textual or visual programming interfaces. It involves the use of algorithms to process input data and generate a result, such as geometry. A key aspect of computational design is the diverse range of complex outcomes that can be achieved (Manavis, Kakoulis & Kyratsis, 2023).

CAD systems' programming is utilized in various industries. Design automation is one of the most important factors as design time is significantly reduced by creating and using various algorithms (Minaoglou et al., 2023; Kyratsis, Manavis & Davim, 2023).

Wearable products are one of the areas where computational design comes to solve a series of problems. A wearable product should schematically maintain a basic form but should be able to be customized to suit its user (Efkolidis et al., 2020).

The primary use of a helmet is to protect the user in the event of a fall or collision with another vehicle. A significant focus of helmet design research involves analyzing digital and physical crash data. Finite element analysis (FEA) is a digital method in which a collision can be simulated in order to collect the appropriate data. In the case of helmet design, the goal is to optimize its performance in a real crash. Optimizations can be made both in the morphology of the design and in the materials to be used (Mills & Gilchrist, 2006).

Each helmet consists of its inner and outer part. Both sections are equally important during helmet impact. By using a different morphology in the inner part of the helmet the shock absorption capacity is increased. The definition of the final shape can be obtained through a series of optimizations. In some research studies, the inner part of the helmet is made using two different materials. Finite element can analyze actual helmet impact tests which are in the final design stage (Teng, Liang & Nguyen, 2014; Deck et al., 2019; Oikawa et al., 2017; Mills & Gilchrist, 2008). The correct fit of a helmet on a user's head is a crucial factor in determining its impact effectiveness. To address this issue, a methodology was developed utilizing 3D anthropometry, reverse engineering techniques, and computational analysis with an aim to establish a helmet fit index. This specific indicator can be used in several phases of helmet design in order to improve it (Perret-Ellena et al., 2014; Zhu et al., 2024).

A series of studies were conducted on both injured and uninjured cyclists. Anthropometric measurements of the cyclists' heads were taken, and questionnaires were developed to assess proper helmet usage. The findings revealed that differences in head shape or improper helmet fit can significantly increase the risk of injury in the event of a collision (Thai, McIntosh & Pang, 2015; Rivara et al., 1999; Pang et al., 2018). Mass customization is a process of creating industrial grade custom products. By dividing a group of users into smaller subgroups of similar anthropometric data (i.e. use of 3D scanning) products can fit the users’ bodies with great accuracy. 3D scanning is a method of digitizing a real object and transferring its geometry to the computer in 3D format (Lužanin & Puškarević, 2015).

The implementation of this process can be based on some fixed and some variable dimensions of a product. In this way, a product can be easily manufactured at an industrial level (Ellena et al., 2018; Skals et al., 2016; Mustafa et al., 2015). An issue frequently encountered in designing wearable products is the lack of precise anthropometric measurements for heads. To address this, a portable 3D scanner was developed to accurately capture the dimensions of a variety of head shapes. This high level of accuracy provided by a 3D scanner system can benefit future research in the design of products intended for use on or around the head (Perret-Ellena et al., 2015).

3D printing is a manufacturing method which in recent years has also been used in the field of helmet design. Several studies have dealt with the creation of new complex structures for the inner part of the helmet, which in order to be manufactured require 3D printing due to their complexity. In many cases, a cellular structure is used which, through various controls, shows better impact results compared to traditional materials. Furthermore, the use of flexible materials can offer the reuse of the helmet even after a fall. The most common 3D printing technologies used in the construction of the inner part of the helmet are Laser Sintering technology and Fused Filament Fabrication (FFF) (Soe et al., 2015; King et al., 2024; King et al., 2022; Decker & Kedziora, 2024).

The process of computational design involves using CAD-based programming to create 3D models, particularly in situations where the model has intricate geometry or requires parameters for both its dimensions and shape (Manavis et al., 2022). The use of mathematics is one of the key elements of computational design as by creating equations, complex geometries and structures can be designed (Jha & Biswal, 2020). In several studies, Grasshopper™ as part of Rhinoceros™ is used to create products that are worn on the head and in general on the human body. In these cases, the algorithm created uses specific input data and can provide as output the final personalized product, that is focused on a specific user (Bai et al., 2021; Man, Tian & Yue, 2022).

The current paper presents an application for the automated design of bicycle helmets. The application uses an algorithm to generate a 3D CAD model of a helmet by collecting data from the user. Two images of the head from different angles serve as the input data for the algorithm. The application results are verified in the study using a second algorithm based on a 3D scanning technique. The application developed is based on Grasshopper™ and automates the customized geometry generation. A specially developed algorithm was implemented with an aim to increase the accuracy of the lines that built the 3D CAD models. Several different geometrical types and shapes are proposed with an aim to further satisfy the customized requirements. At the conclusion of the research, a model bicycle helmet is created using 3D printing technology.

The proposed methodology

Workflow description

Bicycle helmets are designed to protect cyclists, and the main design challenge is ensuring that they fit different head sizes and shapes. The problem is solved by introducing standardized sizes and shapes, such as Small (S), Medium (M), Large (L), and Extra Large (XL). Nevertheless, some users still struggle to find the right size, shape, or both for smooth usage.

The main aim of the proposed research was to create an application (based on computational design principles), which would be able to automate the design of the helmet using 2D images from the user's head. More specifically, using two 2D images, the intricate details of the head were incorporated into a customized helmet design. The core concept of the algorithm focused on generating and analyzing the outer curves of the head. In addition to the initial 2D images-based algorithm, a separate algorithm was developed using 3D data from reverse engineering techniques (e.g. 3D scanning). The second algorithm aimed at verifying the proper functioning of the application. Figure 1 illustrates the workflow of the proposed methodology. More specifically, the discussion focuses on the product category related to bicycle helmet design and manufacturing. The tools utilized include computational design, 3D scanning, photogrammetry, and 3D printing. Computational design was carried out with the assistance of the Grasshopper™ visual programming language within the Rhinoceros3D™ platform.

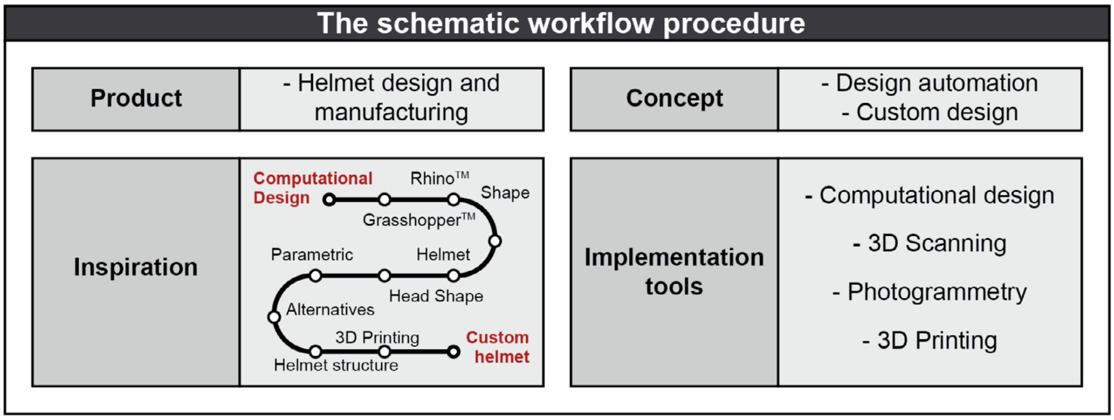
Computational design procedure

The produced algorithm consists of two sub-algorithms named as Code_A and Code_B. Each sub-algorithm varies in both the input data it receives and the way it processes that data. The Code_A starts by inserting and placing the two 2D images from the users' head, followed by their processing to generate the helmet basic outline curves.

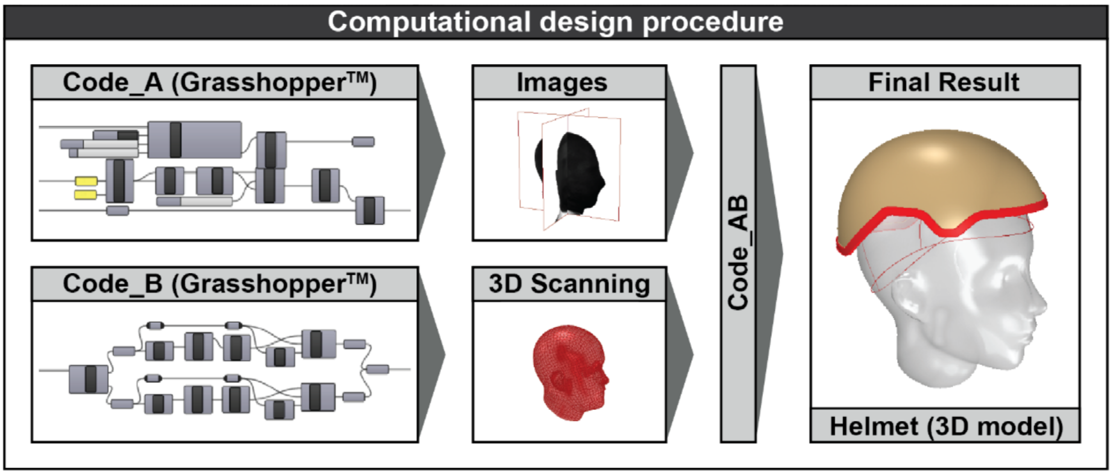
On the other hand, the Code_B begins by inserting and positioning the 3D scan model, then proceeds to process it in order to generate the appropriate guidelines/curves. In the next step, the two sub-algorithms were combined with each other. The final helmet was generated from the output data of both sub-algorithms, but the overall algorithm could still function with just one of them. The Figure 2 shows schematically the procedures of the two sub-algorithms as well as the way they are combined for the final result of Code_AB.

Head shape digitalization

Prior to taking photos of the head, it is crucial to use a stretchy, thin fabric to reduce the volume of the hair, resulting in a more distinct head silhouette.



» **Figure 1:** *Schematic workflow for helmet design and manufacturing*



» **Figure 2:** *The combined sub-algorithms that produced the final result*

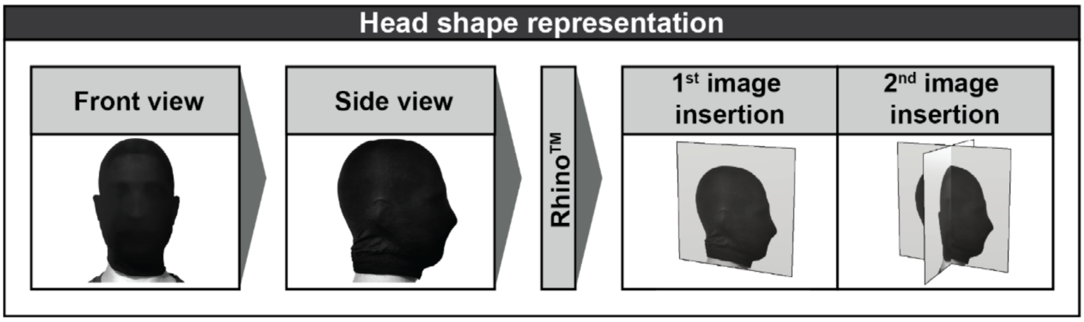
Following this, two 2D images were taken from different angles to provide the algorithm with the necessary data on the head's shape, using a minimal number of viewpoints for user convenience.

Furthermore, in order to determine the size of the images accurately, the user must provide the diameter of the head from the forehead to the back of the head (above the neck) along with the two photos. This dimension will be inserted into the algorithm following the creation of the curves to ensure proper sizing. Figure 3 demonstrates that the fabric is black against a white background, which aids the algorithm in a later phase. The two 2D images are condensed into a 1000x1000-pixel frame, loaded into the algorithm, and arranged at right angles to each other. Subtle adjustments are then made to the images to align their edges.

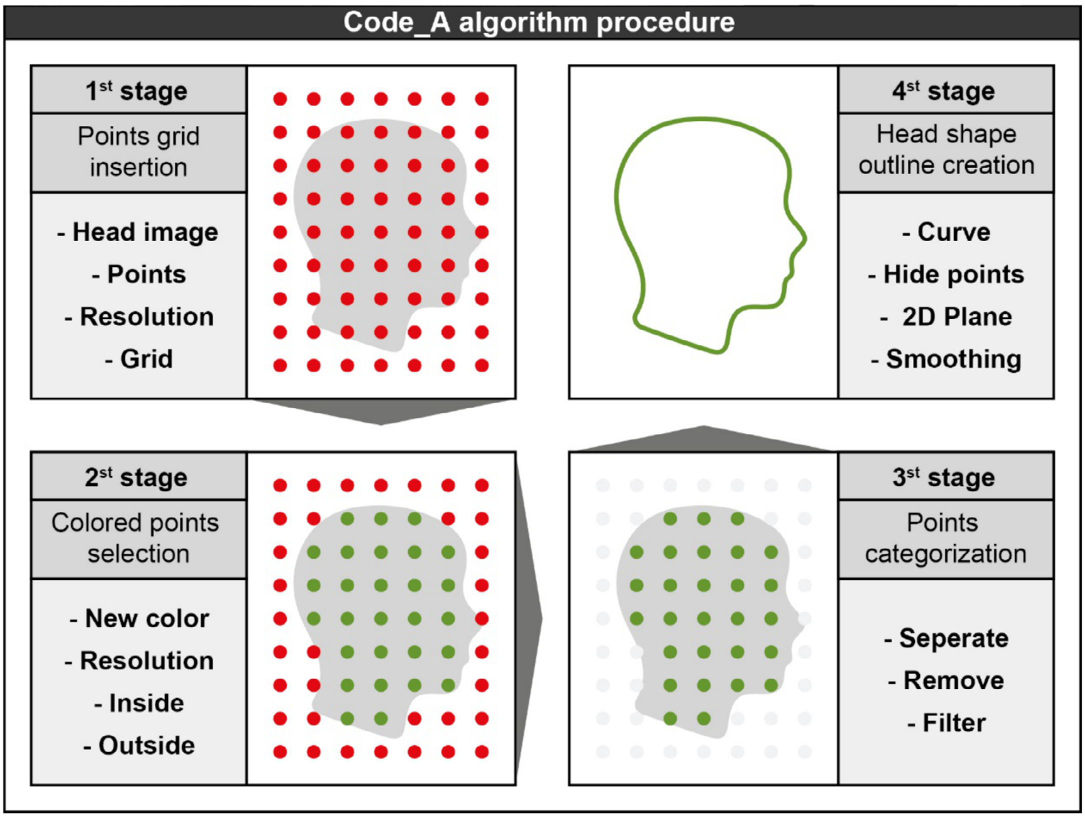
Head shape representation via Code_A algorithm

The main goal of the Code_A algorithm is to create curves that follow the actual shape of the user's head. Code_A consists of four generation stages, which are shown schematically in Figure 4.

The first stage involves creating a grid of points that is bounded by the image, with the number of points determining the initial curve quality. In the second stage, points are categorized based on the color of their corresponding image area. The third stage involves collecting and filtering points from dark areas of the image. Finally, in the fourth stage, a curve is generated by tracing the outline of the points. These four stages are then repeated for the second image.



» **Figure 3:** *Head shape digitalization via image processing*



» **Figure 4:** *Stages of head shape representation*

In the initial phase of Code_A, a grid of 10,000 points is generated for each image, equating to a ratio of 1:100 points per pixel from a total of 1,000,000 pixels. This number of points ensures the algorithm operates effectively within a 10-second computing time constraint. It is important to highlight that utilizing a 1:1 ratio would significantly lengthen the computation time needed by 100 times. After the first stage is completed, it is recommended to use proportions close to a 1:1 point/pixel ratio for optimal curve accuracy.

The RGB color code is then utilized to categorize points in bright and dark areas of the image. Each color in the RGB coding can range from 0 to 255, with 0 representing the absence of color and 255 representing the full presence of color.

By multiplying the color values together, a number is generated for each point, indicating the amount of color present in that area. Points in bright areas will have lower numbers approaching 0, while points in dark areas will have higher numbers approaching 16,581,375 (255^3). This difference in number size divides the points into two main categories (inside and outside of the head shape).

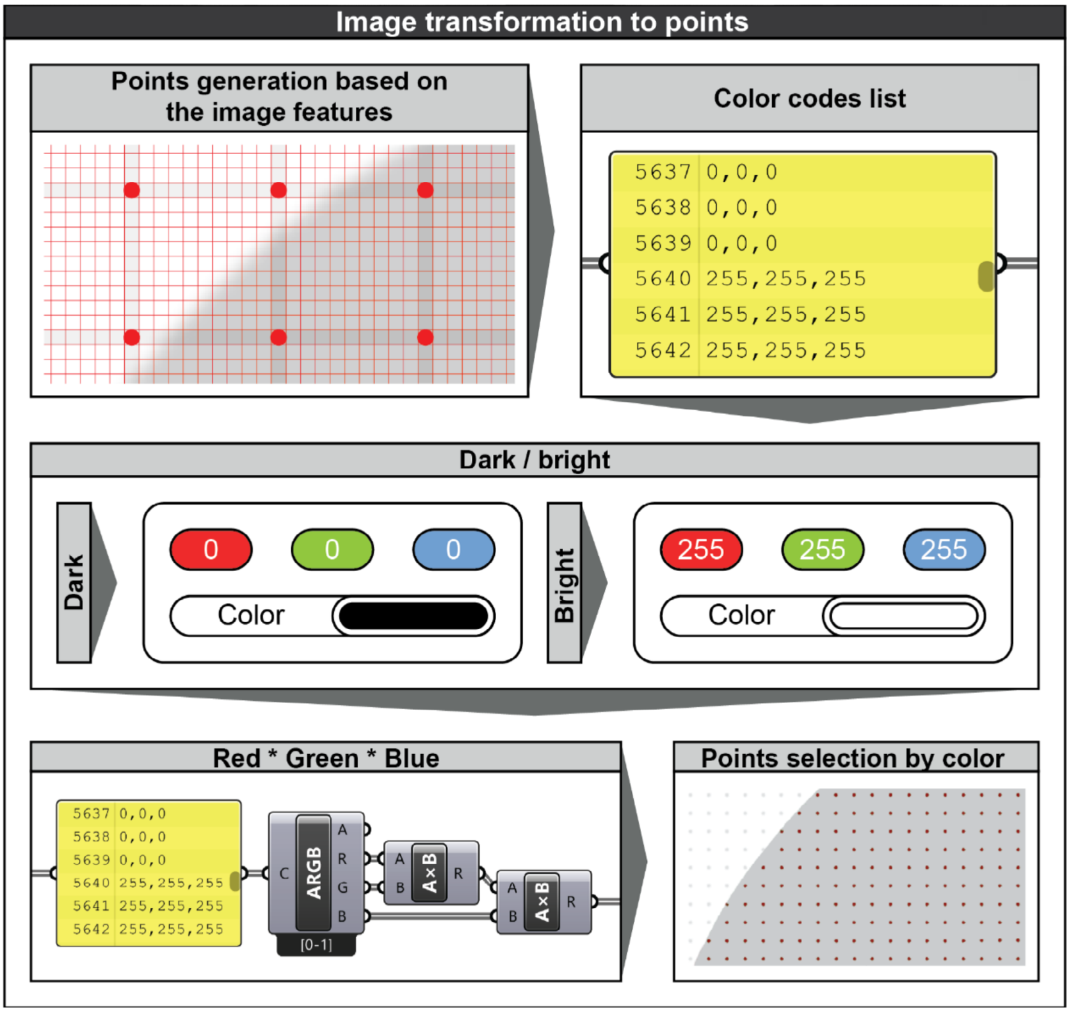
Keeping the points of the dark areas, we have in our possession the points which are located in the area of the head. Corresponding algorithms for pixel management can be found in the bibliography (Chahdi et al., 2021; Laraqui, Laraqui & Saaidi, 2023).

Figure 5 depicts the above-described stages of Code_A.

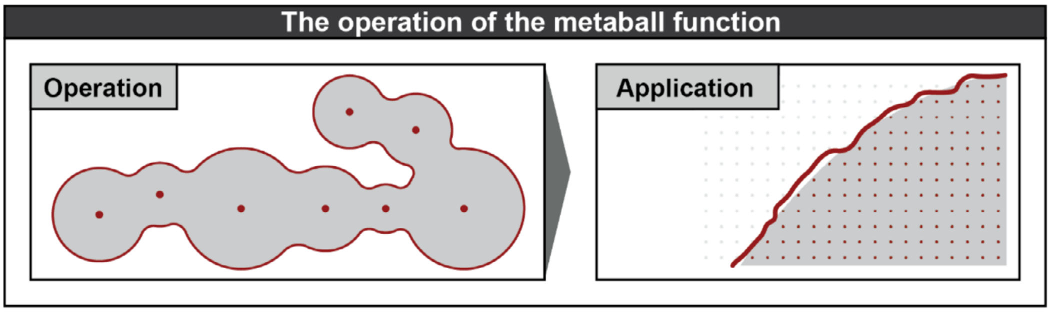
Head shape outline smoothness

The head's shape is determined by a collection of points situated both within it and along its perimeter. The metaball function is a technique that generates closed shapes centered around the specified points. Along with the points, the metaball function utilizes an additional variable to generate circles around each point.

The circles' sizes are designed to eliminate any gaps in the grid by covering the distance between the points. More specifically the size of the circles declared in the metaball function was: R = (PtD / 2) + (0.8 * PtD), where (R) the radius of circles and where (PtD) the distance of the points. The metaball function was applied to the selected points and the result is shown in Figure 6.



» **Figure 5:** *Points generation and selection based on the image colors features*



» **Figure 6:** *Metaball function application to the selected points*

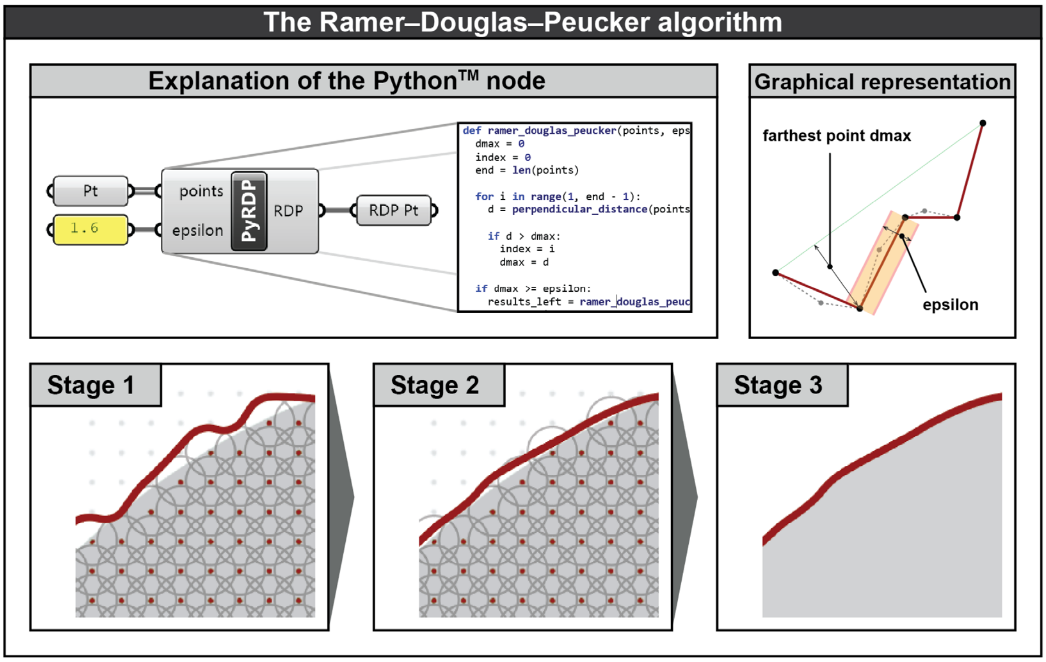
The Ramer-Douglas-Peucker (RDP) algorithm is a curve smoothing procedure (Ramer, 1972). The goal of this specific algorithm is to simplify a polygon by reducing the number of its vertices, i.e. producing a similar polygon with fewer points.

The main features of the algorithm are: a) the iterative method for checking and generating polygons, b) the use of the epsilon variable as a fitting criterion, and c) the output which is a subset of the points determined at the beginning of the algorithm. In this particular study, the algorithm was designed using the Python™ programming language and stored in a GhPython Script™ component named PyRDP. The input data is defined through the variables points and epsilon, while the result of the algorithm is exported through the variable RDP.

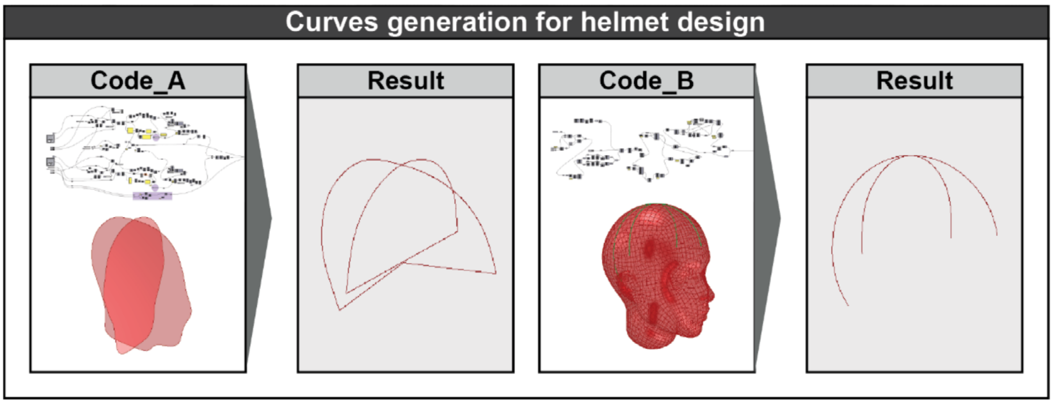
Figure 7 illustrates three stages of implementing PyRDP in the research algorithm. The first stage shows the circles of the metaball function along with its outer polygon outline. In the second stage, the outcome of applying PyRDP to the polygon is shown. Lastly, the third stage presents the new polygon in relation to the curve of the head.

3D scanning integration

In the last part of Code_A, the two polygons representing the front and side views were transformed into curves. Using the dimensions of these curves and considering the user's circumference, a third curve was created, which corresponds to the top view of the head. The measurement of head circumference is affected by factors such as the user's age, height, and gender (Bushby et al., 1992). Additionally, the contour shape can be crafted by combining two 2D shapes: a circle and an ellipse (Ball et al., 2010). With the upper bounds obtained from the other two curves, the combined shape to the endpoints of these curves were aligned. This process results in a three-dimensional wireframe model that takes on the form of a head. Details pertaining to the face, ears, and neck are eliminated by systematically erasing the front and side curves. Simultaneously, while developing Code_A, we also work on the design of Code_B. Specifically, this involves integrating the 3D scanned head into the algorithm. By utilizing three planes along with the 3D geometry, the algorithm calculates the intersection curves between the geometries.



» **Figure 7:** *Curve smoothing utilizing an algorithm in the Python™*



» **Figure 8:** *The high accuracy outcomes of the Code_A and Code_B procedures*

This process results in the generation of a new wireframe that outlines the shape of the head. At this stage, a comparison is conducted between Code_A and Code_B to verify the proper functioning of Code_A. Figure 8 displays both Code_A and Code_B, along with their outcomes in 3D space and their high accuracy.

Helmet 3D CAD modeling

Curves were generated by utilizing the control points of each polygon. The endpoints of these curves on all three sides were assessed based on their spatial positions.

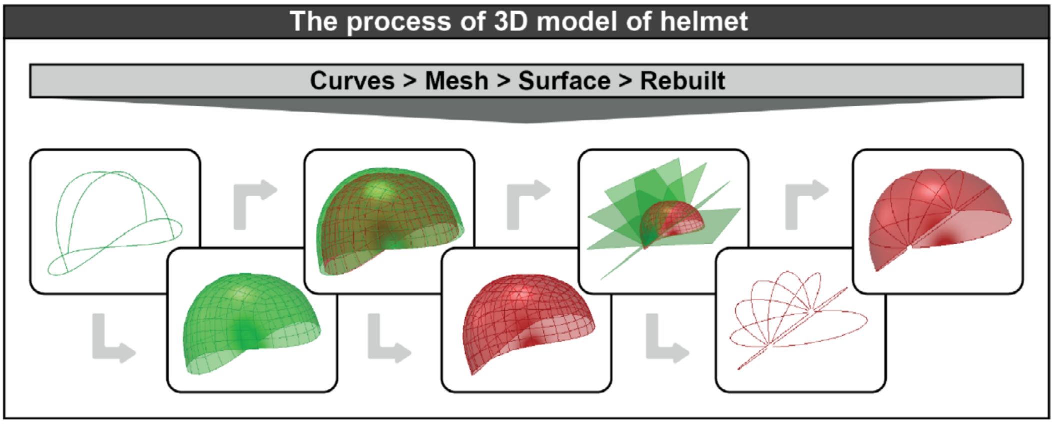
This step is crucial for accurately drawing a surface that conforms to the wireframe. Simultaneously, symmetry was established between the right and left sides of the wireframe. This symmetry was achieved through the development of an average curve, calculated from the average absolute coordinate values. By curving the polygons, connecting the endpoints, and ensuring symmetry within the wireframe, it was made ready for conversion into a mesh. The mesh is constructed from 318 surface squares, which are further divided into smaller squares using the subdivision command. Next, the surface is shifted parallel using an offset to create a gap that defines the internal geometry of the helmet. Subsequently, the mesh is segmented with surfaces to generate new curves.

These new curves are then used to create a surface with an updated topology. This new topology will be beneficial in the later stages of the design process for adding additional features. Figure 9 illustrates the various stages of the helmet modeling process.

Every helmet consists of two main parts which are the outer part and the inner part. The role of the inner part is to absorb shock in the event of a fall. Materials are usually chosen based on their properties and can absorb external loads to protect the head. The role of the outer part is to contain and protect the inner part.

The algorithm generates these two components based on the dimensions of the surface. Additional features and details were incorporated into the helmet's design, such as holes on the sides and a retaining strap. Figure 10 illustrates these features in various colors, with the outer section depicted in red and the inner section in yellow.

In the continuation of the algorithm, the goal was to parameterize the shape of the helmet around the perimeter. More specifically, four sidecut geometries Shape_1, Shape_2, Shape_3 and Shape_4 were created. All geometries consist of curves, which keep their ends at the same points. The differentiation of the geometries is carried out inside each shape.



» **Figure 9:** *Bicycle helmet design step by step*

Figure 11 shows the geometries from Shape_1, Shape_2, Shape_3 and Shape_4 in 2D view. Furthermore, the results from applying the geometries to the final helmet are presented in a 3D view.

Using the same methodology, the upper section of the helmet is parameterized. Specifically, six different geometries are created for this part, labeled Type_1, Type_2, Type_3, Type_4, Type_5, and Type_6. These geometries are then used to modify the helmet, leading to the formation of internal holes. Figure 12 illustrates the 2D representations of Type_1 through Type_6. Additionally, the outcomes of applying these geometries to the final helmet are displayed in a 3D perspective.

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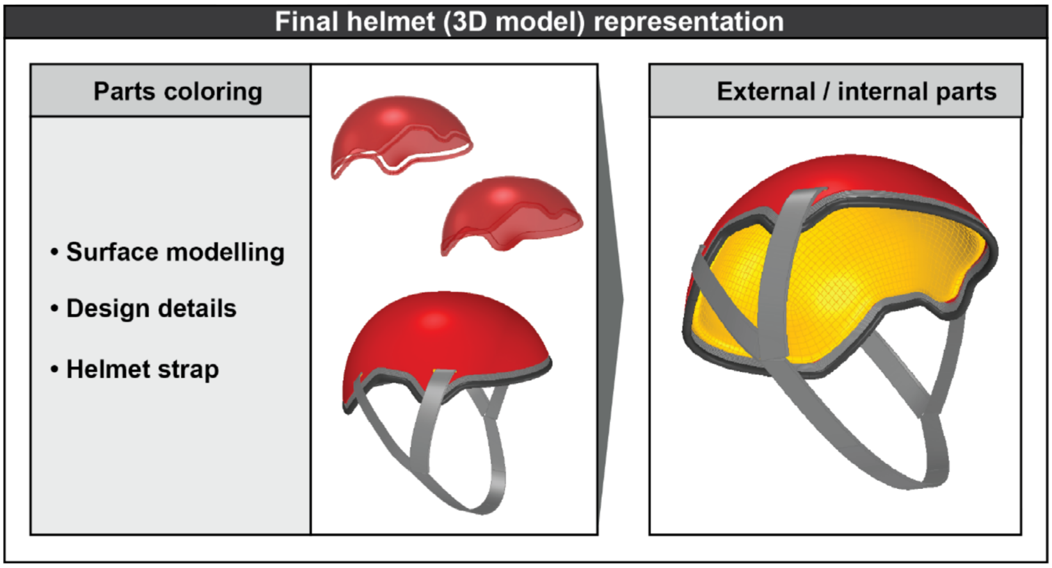
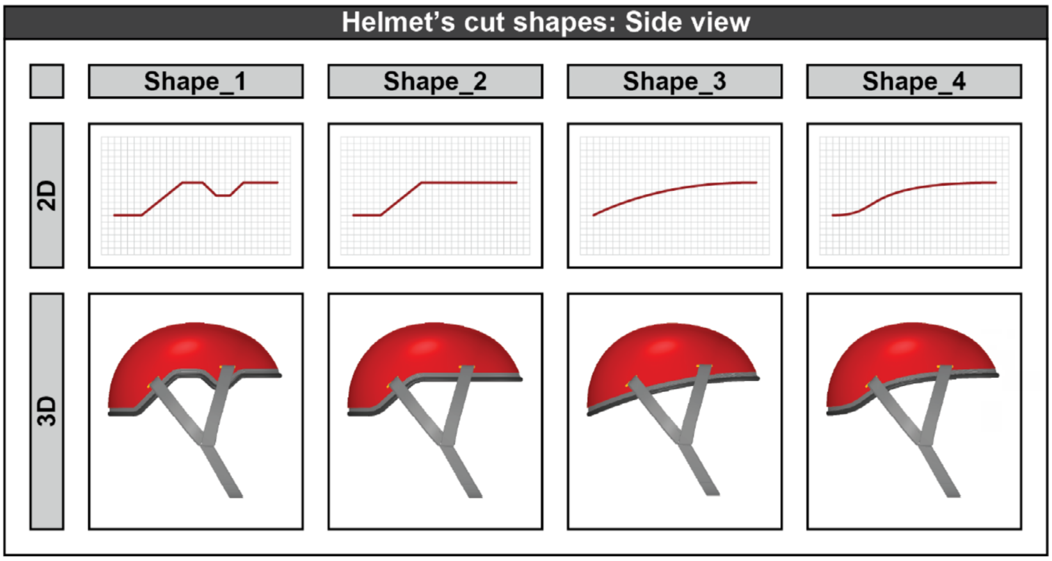
At this stage, all examples of helmet creation using the combinations of Type_1-6 and Shapes_1-4 have been presented. As illustrated in Figure 13, the parameterizations for the helmet shape were consistently applied across all combinations. The algorithm was designed to ensure that the geometries of the shapes do not interfere with one another.

One technique employed to prevent discrepancies is adjusting the shape proportions relative to the helmet's overall size.



» **Figure 10:** *Helmet's design architecture*



» **Figure 11:** *Representation of helmet's cutting shapes: Side view*

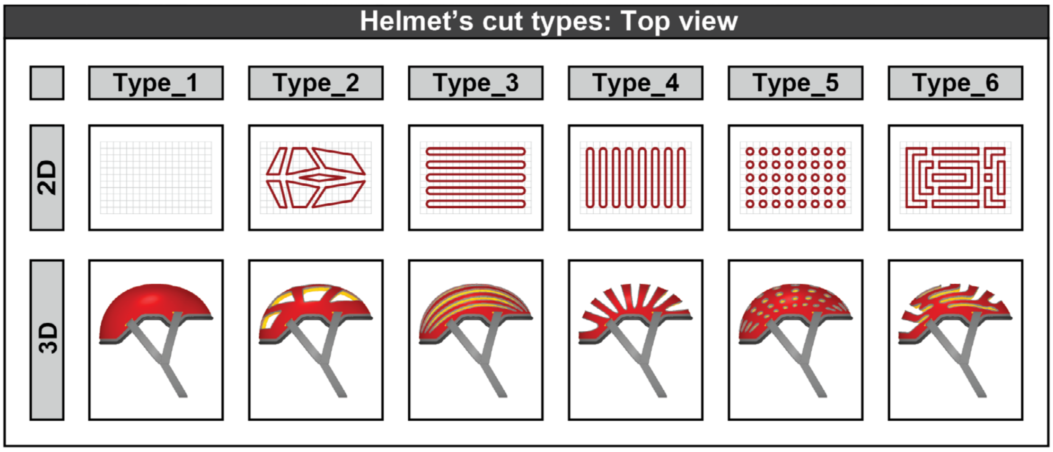
Essentially, if the head dimensions are below average, the Type_1-6 and Shapes_1-4 will adapt to fit the new size.

3D printing

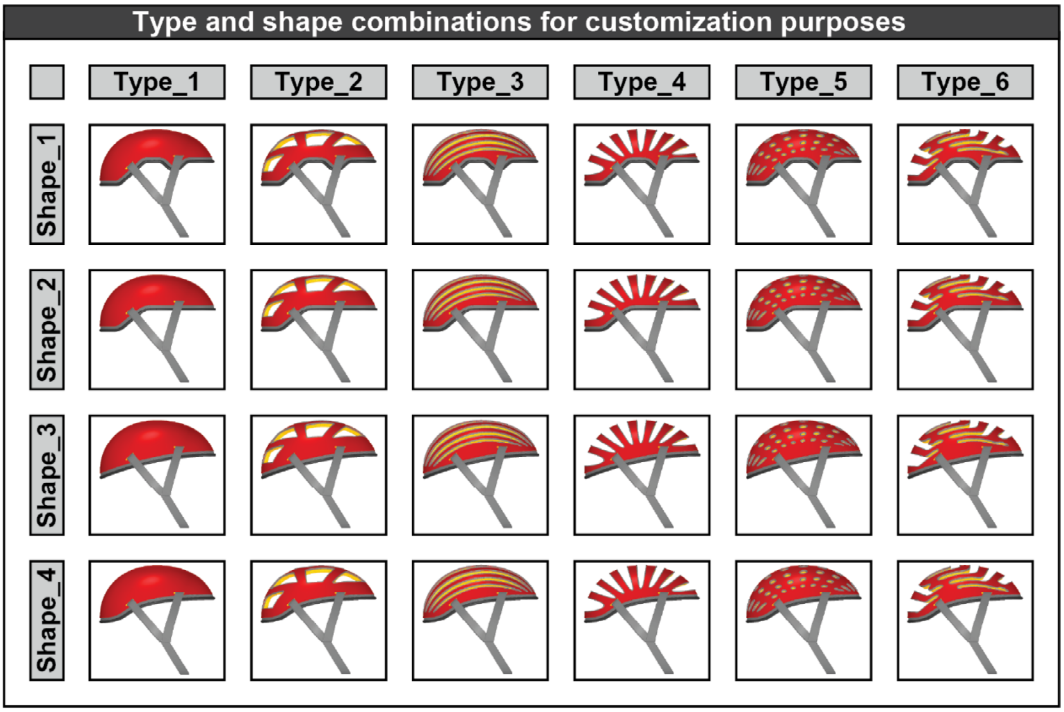
A helmet prototype was created using the 3D printing method. The materials used are s CARBON: PLUS (NEEMA3D™, Athens, Greece) and CR-TPU (Shenzhen Creality 3D Technology Co., Shenzhen, China). CARBON: PLUS is a PET-G based material reinforced with 20% carbon fiber. The carbon fibers give the material a very high resistance to stiffness, impact and heat. And they also affect its specific gravity, which is 1.19 g/cc.

The printing settings for the CARBON: PLUS material are: Layer = 0.1 mm, Wall = 2.4 mm, Flow = 115%, Nozzle Temperature = 245ºC, Infill = 100% and Printing Speed = 40 mm/s. These values optimize the strength measured in tension which reaches σ = 98.48 MPa.

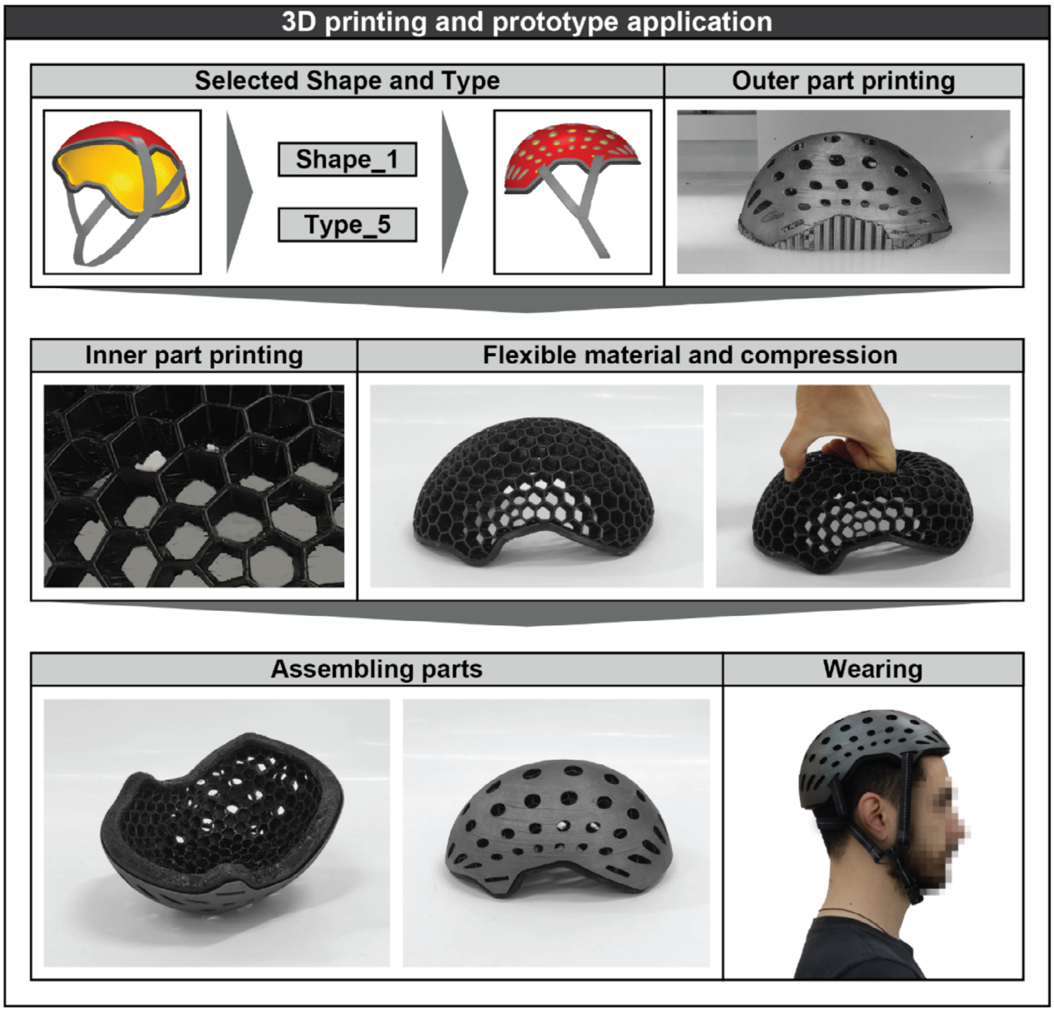
The optimization of the settings was found based on the RSM (Response Surface Methodology) research published (Minaoglou et al., 2024). CR-TPU is a flexible material which, depending on its internal structure, can absorb different shocks. This material can be stretched up to 500% before breaking and its specific gravity is 1.16 g/cc. CARBON: PLUS will be used for the outer part of the helmet and CR-TPU for the inner part. The printer used for this particular prototype print was the CreatBot™ D600 Pro (Henan Creatbot Technology Limited, Zhengzhou, China) which belongs to the FFF (Fused Filament Fabrication) 3D printer category (Figure 14).



» **Figure 12:** *Representation of helmet's cutting types: Top view*



» **Figure 13:** *Helmet combinations for customization purposes*



» **Figure 14:** *Helmet prototyping procedure and application*

Conclusions

Computational design is a tool that helps automating various processes. In this study, the computational design algorithm comes to automate the CAD-based design process of a custom cyclist helmet. The algorithm is using two photographs of a user's head and as a result it can design the helmet, which will be able to fully match the morphological characteristics and dimensions of the user. The algorithm used was divided into two sub-algorithms. The two algorithms use different procedures with an aim to arrive at the same result. More specifically, the first algorithm designs the helmet frame through the use of two photos, while the second one through a 3D scanned model of the head. 3D scanning is a tool that is not readily available for every use. The purpose of the first algorithm is to replace 3D scanning using two photos.

The first algorithm is the basic process of the application, while the second comes to checking the correct operation of the first. Based on the results of using the application on real users, there was no significant deviation between the results from the two sub-algorithms.

By controlling some parameters of the algorithm, the deviation between the results can be greatly reduced. In the context of the study, the application was designed with the aim of being able to parameterize the shape of the helmet, giving the user some predefined external appearance and shape options. The specific shape parameterizations did not create any problem neither in their combined application nor in their application to helmets with very large or small dimensions. At each size change the parameterizations were adjusted to the new data.

At the end of the study, 3D printing was performed using two NEEMA3D™ CARBON materials: PLUS and CREALITY CR-TPU. The printed helmet was tested by its user without any difficulty. The dimensions and curvature of the inner part of the helmet presented a uniform fit on the head.

This particular application could be expanded with more functions and automations in the future. For example, searching for the location of eyes and ears using photos could evolve the app. Also, Artificial Intelligence AI is a tool that could improve how the algorithm works.

Finally, Computer-aided design (CAD) has become a fundamental aspect of product design and manufacturing in today's industry. The incorporation of advanced technologies plays a crucial role in developing unique products tailored to meet user needs. Future research in this study could focus on determining the optimal internal geometric structure of a helmet and Computer-Aided Engineering (CAE) evaluation of different structural designs to maximize safety for cyclists.

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References

Bai, X., Huerta, O., Unver, E., Allen, J. & Clayton, J. E. (2021) A Parametric Product Design Framework for the Development of Mass Customized Head/Face (Eyewear) Products. *Applied Sciences*. 11 (12), 5382. Available from: doi: 10.3390/app11125382

Ball, R., Shu, C., Xi, P., Rioux, M., Luximon, Y. & Molenbroek, J. (2010) A comparison between Chinese and Caucasian head shapes. *Applied Ergonomics*. 41 (6), 832–839. Available from: doi: 10.1016/j.apergo.2010.02.002

Bushby, K. M., Cole, T., Matthews, J. N. & Goodship, J. A. (1992) Centiles for adult head circumference. *Archives of Disease in Childhood.* 67 (10), 1286–1287. Available from: doi: 10.1136/adc.67.10.1286

Chahdi, A. O., Ragragui, A., Halli, A. & Satori, K. (2021) Per-pixel displacement mapping using cone tracing with correct silhouette. *Journal of Graphic Engineering and Design*. 12 (4), 39–61. Available from: doi: 10.24867/JGED-2021-4-039

Deck, C., Bourdet, N., Meyer, F. & Willinger, R. (2019) Protection performance of bicycle helmets. *Journal of Safety Research.* 71, 67–77. Available from: doi: 10.1016/j.jsr.2019.09.003

Decker, T. & Kedziora, S. (2024) Optimizing the thickness of functionally graded lattice structures for high-performance energy absorption: a case study based on a bicycle helmet. *Applied Sciences.* 14 (7), 2788. Available from: doi: 10.3390/app14072788

Efkolidis, N., Minaoglou, P., Aidinli, K. & Kyratsis, P. (2020) Computational design used for jewelry. In: *Proceedings - 10th International Symposium on Graphic Engineering and Design, GRID 2020, 12–14 November 2020, Novi Sad, Serbia.* Novi Sad, University of Novi Sad, Faculty of Technical Sciences, Department of Graphic Engineering and Design. pp. 531–536. Available from: doi: 10.24867/GRID-2020-p60

Ellena, T., Mustafa, H., Subic, A. & Pang, T. Y. (2018) A design framework for the mass customization of custom-fit bicycle helmet models. *International Journal of Industrial Ergonomics.* 64, 122–133. Available from: doi: 10.1016/j.ergon.2018.01.005

Jha, P. & Biswal, B. B. (2020) A mathematical approach for creative graphics design. *Journal of Graphic Engineering and Design.* 11 (1), 37–43. Available from: doi: 10.24867/JGED-2020-1-037

King, A. R. A., Rovt, J., Petel, O. E., Yu, B. & Quenneville, C. E. (2024) Evaluation of an elastomeric honeycomb bicycle helmet design to mitigate head kinematics in oblique impacts. *Journal of Biomechanical Engineering.* 146 (3), 1–10. Available from: doi: 10.1115/1.4064475

King, A. R. A., Tyedmers, A., Gonder, S., Yu, B. & Quenneville, C. E. (2022) Design of a nature-inspired honeycomb bicycle helmet for prevention of traumatic brain injury. In: *The 17th Annual Injury Biomechanics Symposium, 18–19 May 2022, Columbus, Ohio*, Columbus, The Ohio State University Injury Biomechanics Research Center.

Kyratsis, P., Manavis, A. & Davim, J. P. (2023) *Computational design and digital manufacturing.* Cham, Springer Nature. Available from: doi: 10.1007/978-3-031-21167-6

Laraqui, A., Laraqui, M. & Saaidi, A. (2023) Fast mosaicing method based on image resizing pre-processing. *Journal of Graphic Engineering and Design.* 14 (1), 37–47. Available from: doi: 10.24867/JGED-2023-1-037

Leng, B., Ruan, D. & Tse, K. M. (2022) Recent bicycle helmet designs and directions for future research: a comprehensive review from material and structural mechanics aspects. *International Journal of Impact Engineering.* 168, 104317. Available from: doi: 10.1016/j.ijimpeng.2022.104317

Lužanin, O. & Puškarević, I. (2015) Investigation of the accuracy of close-range photogrammetry—a 3D printing case study. *Journal of Graphic Engineering and Design.* 6 (2), 13–18. Available from: doi: 10.24867/JGED-2015-2-013

Man, K., Tian, W. & Yue, F. (2022) A design method of sports protective gear based on periodic discrete parameterization. In: *24th International Conference on Human–Computer Interaction, HCII 2022, 26 June – 1 July 2022.* Cham, Springer. pp. 77–89. Available from: doi: 10.1007/978-3-031-05890-5_6

Manavis, A., Firtikiadis, L., Spahiu, T., Efkolidis, N. & Kyratsis, P. (2022) Parametric architectural design using shapes and structures. *Journal of Graphic Engineering and Design.* 13 (4), 13–20. Available from: doi: 10.24867/JGED-2022-4-013

Manavis, A., Kakoulis, K. & Kyratsis, P. (2023) A brief review of computational product design: a brand identity approach. *Machines.* 11 (2), 232. Available from: doi: 10.3390/machines11020232

Mills, N. J. & Gilchrist, A. (2006) Bicycle helmet design. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications.* 220 (4), 167–180. Available from: doi: 10.1243/14644207JMDA100

Mills, N. J. & Gilchrist, A. (2008) Finite-element analysis of bicycle helmet oblique impacts. *International Journal of Impact Engineering.* 35 (9), 1087–1101. Available from: doi: 10.1016/j.ijimpeng.2007.05.006

Minaoglou, P., Kakoulis, K., Manavis, A. & Kyratsis, P. (2023) Computational wearables design: shoe sole modeling and prototyping. *International Journal of Modern Manufacturing Technologies.* 15 (2), 143–151. Available from: doi: 10.54684/ijmmt.2023.15.2.143

Minaoglou, P., Tzotzis, A., Efkolidis, N. & Kyratsis, P. (2024) Influence of the 3D printing fabrication parameters on the tensile properties of carbon-based composite filament. *Applied Mechanics.* 5 (4), 745–761. Available from: doi: 10.3390/applmech5040041

Mustafa, H., Pang, T. Y., Perret-Ellena, T. & Subic, A. (2015) Impact attenuation of customized user-centered bicycle helmet design. In: *7th Asia-Pacific Congress on Sports Technology, APCST 2015, Procedia Engineering 112, 23–25 September 2015, Barcelona, Spain.* Amsterdam, Elsevier. pp. 77–84. Available from: doi: 10.1016/j.proeng.2015.07.179

Oikawa, S., Nakadate, H., Zhang, Y., Ueno, T., Aomura, S. & Matsui, Y. (2017) Finite element analysis of the effectiveness of bicycle helmets in head impacts against roads. *Journal of Biomechanical Science and Engineering.* 12 (4), 17–00175. Available from: doi: 10.1299/jbse.17-00175

Pang, T. Y., Lo, T. S. T., Ellena, T., Mustafa, H., Babalija, J. & Subic, A. (2018) Fit, stability and comfort assessment of custom-fitted bicycle helmet inner liner designs, based on 3D anthropometric data. *Applied Ergonomics.* 68, 240–248. Available from: doi: 10.1016/j.apergo.2017.12.002

Perret-Ellena, T., Skals, S. L., Subic, A., Mustafa, H. & Pang, T. Y. (2015) 3D anthropometric investigation of head and face characteristics of Australian cyclists. In: *7th Asia-Pacific Congress on Sports Technology, APCST 2015, Procedia Engineering 112, 23–25 September 2015, Barcelona, Spain.* Amsterdam, Elsevier. pp. 98–103. Available from: doi: 10.1016/j.proeng.2015.07.182

Perret-Ellena, T., Subic, A., Pang, T. Y. & Mustafa, H. (2014) The helmet fit index: a method for the computational analysis of fit between human head shapes and bicycle helmets. In: *Proceedings of the 2nd International Congress on Sport Sciences Research and Technology Support, icSPORTS, 24–26 October 2014, Rome, Italy.* Setúbal, SciTePress. pp. 145–153. Available from: doi: 10.5220/0005084101450153

Ramer, U. (1972) An iterative procedure for the polygonal approximation of plane curves. *Computer Graphics and Image Processing.* 1 (3), 244–256. Available from: doi: 10.1016/S0146-664X(72)80017-0

Rivara, F. P., Astley, S. J., Clarren, S. K., Thompson, D. C. & Thompson, R. S. (1999) Fit of bicycle safety helmets and risk of head injuries in children. *Injury Prevention.* 5 (3), 194–197. Available from: doi: 10.1136/ip.5.3.194

Skals, S., Ellena, T., Subic, A., Mustafa, H. & Pang, T. Y. (2016) Improving fit of bicycle helmet liners using 3D anthropometric data. *International Journal of Industrial Ergonomics.* 55, 86–95. Available from: doi: 10.1016/j.ergon.2016.08.009

Soe, S. P., Martin, P., Jones, M., Robinson, M. & Theobald, P. (2015) Feasibility of optimizing bicycle helmet design safety through the use of additive manufactured TPE cellular structures. *International Journal of Advanced Manufacturing Technology.* 79, 1975–1982. Available from: doi: 10.1007/s00170-015-6972-y

Teng, T. L., Liang, C. C. & Nguyen, V. H. (2014) Innovative design of bicycle helmet liners. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications.* 228 (4), 341–351. Available from: doi: 10.1177/1464420713493590

Thai, K. T., McIntosh, A. S. & Pang, T. Y. (2015) Bicycle helmet size, adjustment, and stability. *Traffic Injury Prevention.* 16 (3), 268–275. Available from: doi: 10.1080/15389588.2014.931948

Zhu, Z., Huang, Y., Ji, W., Zhu, J. & Wang, W. (2024) A parametric design framework for the mass customization of bicycle helmet. *Heliyon.* 10 (5), e27409. Available from: doi: 10.1016/j.heliyon.2024.e27409