# REAL-TIME PARAMETRIC CAD FRAMEWORK FOR CUSTOMIZABLE FURNITURE

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**ABSTRACT:** Algorithmic and computer-aided product development have transformed manufacturing workflows by enabling the rapid generation of accurate 3D models through parametric and rule-based methods. Such approaches support mass customization, reduce design time, and improve product consistency. In the furniture sector, CAD-driven processes have enhanced functional performance and production efficiency; however, manual modeling of customized interior components remains labor-intensive and prone to design inconsistencies. This study proposes a real-time parametric CAD framework for the automated design and configuration of modular kitchen-island furniture. The system integrates user-defined dimensions, functional constraints, and module selection through an interactive configuration interface, while automatically generating three-dimensional part models, assemblies, and manufacturing-ready 2D technical drawings. In contrast to existing rule-based or parametric kitchen design systems that primarily address geometric modeling or layout configuration, the proposed framework supports real-time user-driven parametrization and automated generation of manufacturing-related outputs, directly linking design configuration with fabrication-oriented deliverables within a unified CAD environment. Additional outputs, including photorealistic renderings and a complete Bill of Materials (BOM), support decision-making throughout the production workflow. The automated process improves dimensional accuracy, reduces repetitive modeling tasks, and ensures consistency across customized product variants, demonstrating the potential of CAD-based automation for mass-customizable furniture manufacturing.

**KEYWORDS**: *Parametric Design, Computer-Aided Design (CAD), Design Automation, Modular Furniture, Mass Customization*

## 1.0 INTRODUCTION

Algorithmic design is a continuously evolving approach that integrates computational logic into the creative and engineering design process. Digital models and products are developed through advanced Computer-Aided Design (CAD) systems and algorithms, enabling the generation of complex geometries and adaptable solutions [1–2]. This methodology allows designers to simulate, analyze, and refine design alternatives more efficiently than traditional approaches, enhancing adaptability and reducing development time [3–6]. Algorithmic design has been widely applied in mechanical engineering, architecture, and interior design, delivering functional and sustainable solutions [7]. In the context of furniture development, parametric design supports innovation and production efficiency by enabling adaptable configurations and mass customization while maintaining architectural and environmental constraints [8–9]. Digital platforms further facilitate this process by automating workflows and allowing users to define parameter values that directly influence product configuration [10]. As a result, parametric approaches have been applied across various sectors, including kitchen and office furniture, demonstrating improvements in both design and production processes [11–15].

The kitchen represents one of the most functionally demanding spaces in residential environments, integrating work surfaces, storage units, and appliances within limited spatial conditions. Ergonomics plays a central role in kitchen design, aiming to enhance usability, safety, and efficiency through the consideration of anthropometric data and user behavior [16]. Moreover, the kitchen has evolved from a purely functional workspace into a central architectural element of the home, reflecting changes in lifestyle, aesthetics, and hygiene considerations over time [17–18]. Several studies have examined spatial design rules, user needs, and layout constraints to improve kitchen functionality and personalization [19–21]. The spatial organization of kitchens must balance design rules with functional requirements, and established principles such as the kitchen work triangle remain widely used to support ergonomic efficiency [22–25]. In recent years, several studies have focused on automating kitchen layout generation using rule-based and parametric approaches. Automated systems have been developed to generate functional kitchen layouts based on predefined design practices and expert-defined parameters, achieving satisfactory design accuracy and efficiency [26–28]. Parametric methods have also been applied to kitchen island design, enabling geometric variability and optimization through adjustable parameters [29]. While these approaches improve flexibility during early-stage design, they primarily focus on geometric configuration or layout definition.

Beyond layout generation, research has explored structural validation using the Finite Element Method (FEM), artificial intelligence, human-centered design, and interactive systems in the context of furniture and interior environments [30–35]. Parametric tools combined with Building Information Modelling (BIM) have also been applied to support design automation, assembly planning, and mass customization in architectural and interior design workflows [36–40]. In parallel, manufacturing-oriented studies have addressed production efficiency, material selection, and automated generation of design documentation and Bill of Materials (BOMs) to support customized furniture production [41–44]. Although these studies provide valuable contributions, they often address isolated aspects of the design or manufacturing process. Despite significant advances in parametric and rule-based furniture design, a gap remains in the development of integrated frameworks that connect real-time design configuration with automated generation of manufacturing-ready outputs. Many existing systems require extensive manual effort to translate configured designs into technical drawings, Bills of Materials, and fabrication files, limiting their applicability in advanced manufacturing environments.

This study aims to address this gap by developing an automated parametric CAD framework for the design and configuration of kitchen island furniture. Implemented in Grasshopper™ within the Rhino™ environment, the proposed system enables user-driven definition of dimensions and component selection while automatically generating three-dimensional CAD models, assemblies, detailed technical drawings, Bills of Materials (BOM), STL files for digital fabrication, and photorealistic renderings. By integrating real-time parametric configuration with automated production deliverables within a unified digital workflow, the proposed approach enhances design efficiency, supports mass customization, and provides a complete pipeline from concept development to fabrication.

## 2.0 METHODOLOGY

The layout and design of interior spaces evolve over time in response to changing user needs, functional requirements, and design trends. To address this variability, the present study develops an automated parametric framework for the holistic design and configuration of a kitchen island. The proposed system integrates anthropometric measurements, user requirements, and aesthetic preferences within a CAD environment to support an efficient and user-driven design process. The methodology is structured into three main stages that guide the workflow toward the final outcome. In the first stage, key parameters related to the basic dimensions and component selection of the kitchen island are defined, enabling the automated generation of the product geometry. In the second stage, the components and materials that compose the kitchen island are organized into structured outputs to facilitate communication with manufacturing processes. In the final stage, the product is digitally visualized and exported in its complete form.

The primary objective of the study is to develop a kitchen island that can be directly configured by the user through an interactive application. The application is based on two interconnected parts. The first part is the interactive interface, where users actively participate in the design process by defining the characteristics of the final model through parametric input. The second part concerns the automated system output, in which the selected components, materials, and configuration details are processed and visualized, resulting in the automatic generation of the corresponding three-dimensional model and associated design data. The parametric structure of the application allows users to define the final configuration of the kitchen island by selecting predefined values and options, such as overall dimensions, modular components, accessories, and materials. Once these parameters are specified, the three-dimensional model is generated and updated automatically, reflecting the user's functional and aesthetic preferences in real time. The kitchen island is composed of modular sections that can be combined in multiple configurations, allowing a high level of customization while maintaining design consistency and efficiency across different product variants.

The proposed framework follows a structured parametric workflow which can be defined in three main stages: input definition, algorithmic processing, and output generation. In the input stage, the user defines parameters such as dimensions, modular components, materials, and functional constraints through the interface. These parameters control both the geometry and the overall system behavior. The processing stage uses a rule-based parametric algorithm to divide the kitchen island into modular units. The geometry is generated through predefined rules and conditions, making the design flexible while keeping consistency between components and allowing real-time updates. In the output stage, the system automatically generates design and manufacturing data, including 3D models, assemblies, technical drawings, Bills of Materials (BOM), and STL files. This workflow directly connects the design configuration with fabrication preparation.

## 2.1 Design

To implement the final algorithm of the application, a visual programming language was employed, enabling a more intuitive and modular development process. Specifically, the algorithm was created in Rhino™ in combination with its parametric design extension, Grasshopper™, which allows the definition of logical operations, parameter relationships, and geometric transformations through node-based programming. As shown in Figure 1, the final model of the kitchen island is dynamically generated based on the user's selections, which include parameter values and predefined component options from structured lists. In this way, the model updates in real time according to the design inputs provided by the user.

In addition, to improve the clarity, organization and scalability of the algorithm, the overall workflow was divided into individual clusters. Each cluster corresponds to a specific design function (e.g., dimensional input, component placement, material assignment, or 3D geometry generation), allowing for better management, easier repairing and future modifications. This modular approach ensures a more efficient development process and enhances the flexibility of the parametric system.

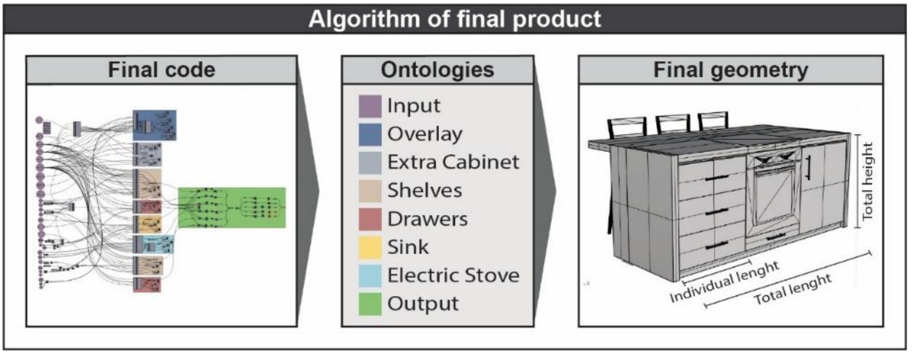



Figure 1: Final result of the island furniture resulting from the use of a visual programming language

In the first phase, the creation of the kitchen island begins with the specification of its total length. This value is critical, as it automatically determines the final number of individual modules that will compose the product. To support this process, a set of commonly used kitchen island elements was selected and designed parametrically. The simplest module consists of an empty box. In this geometry, the length remains constant at 600 mm, while the width and height can vary within specific anthropometric ranges to ensure ergonomic suitability. Beyond the basic box, additional functional elements can be integrated. Shelves and cabinets may be added, and each cabinet can be oriented to open in the most appropriate direction based on the island layout. Drawers are also included to enhance storage functionality, and choosing an optimal number allows for personalized and efficient organization of the kitchen island.

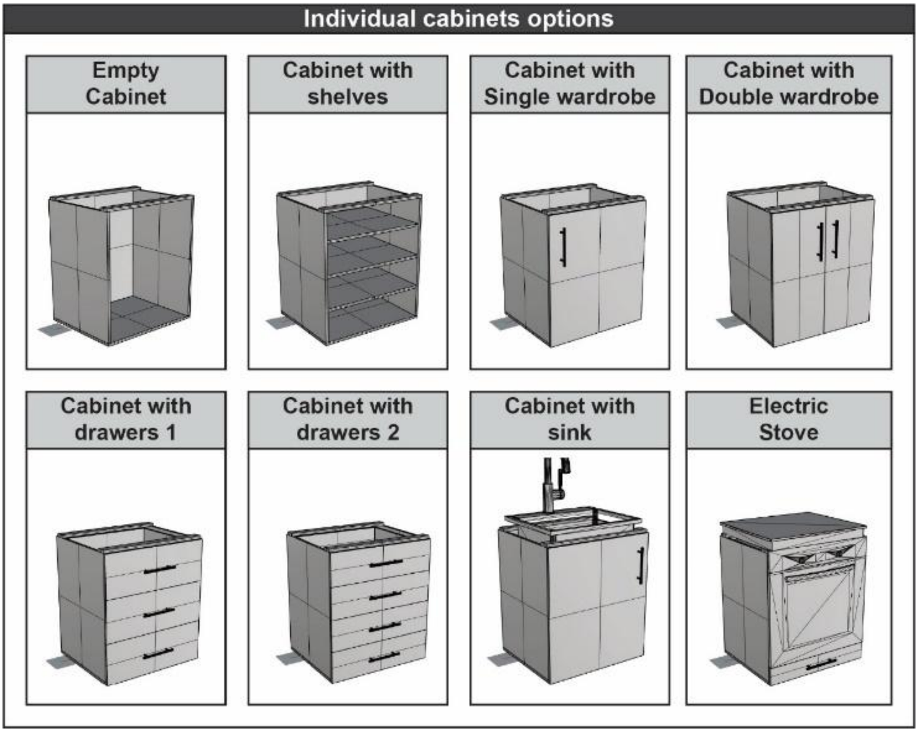



Figure 2: Individual parts for the composition of the final furniture

It is widely recognized that kitchen islands serve multiple purposes beyond storage, such as integrating appliances and work surfaces. Therefore, the system also supports the placement of an electric stove, with or without a hob, as well as a sink. In cases where the total island length is not a multiple of 600 mm, the remaining space is filled with a fixed empty box. An additional level of parameterization is applied to this residual module. If the remaining gap is less than 300 mm, the box remains closed; otherwise, it can function as an additional storage compartment. This conditional logic ensures both functional use of space and design consistency. Figure 2 presents the individual components that may constitute the proposed kitchen island in this study.

At the same time, an additional library of objects was developed, consisting of cabinet components such as hinges, drawer guides and handles, as well as faucets and seating elements. These objects not only serve a functional role in forming the individual cabinet sections and the final composition of the kitchen island, but also fulfill an important aesthetic and customization purpose. Specifically, this library demonstrates the potential to integrate product lists from real manufacturing companies, allowing each user to select specific hardware and accessories that match their personal preferences and the overall style of the interior space where the island will be installed. In this way, the system supports both technical accuracy and market-oriented customization, enhancing the design's realism and applicability in real-world manufacturing scenarios.

## 2.2 Interface

Figures 3 illustrate the application interface, which includes both the input parameters and the resulting outputs. The goal is to provide a simple and intuitive method for selecting the values that concern the user. The interface consists of sliders, option menus and on/off buttons, effectively organizing the available choices for configuring the kitchen island. The simultaneous presentation of the 3D model alongside the parameter inputs creates a familiar and user-friendly environment. In the "General" section, the user defines the overall dimensions of the island, such as total length and height, and can also choose whether an additional auxiliary countertop is required. In the same section, the basic dimensions of the box geometry (depth and wood thickness), as well as the materials of the individual elements of the island, are specified.

The section referring to the boxes is organized according to their types, allowing the user to form the final desired configuration. This list includes shelves, drawers, the sink and the electric stove (main tabs on the left of the interface, under the name "Cabinets"). The main choices concern whether each type of box will be included and in which position, the number of shelves, drawers and cabinets, as well as the number, position and orientation of handles. Regarding the electric stove, the user can choose its position and whether a gas hob is required on the countertop. All these options are made possible through algorithmic design. The defined parameters provide a wide range of choices, enabling the user to configure a kitchen island that meets their functional and aesthetic needs within the home. The "Extras" tab allows the selection of handle types, faucet and stools. The extensive product lists enable users to choose their preferred items that match their aesthetic preferences. Finally, the "Export" section provides information about the individual parts and the 3D model along with its dimensions. Additionally, photorealistic renderings, STL files and a Bill of Materials are generated and exported.

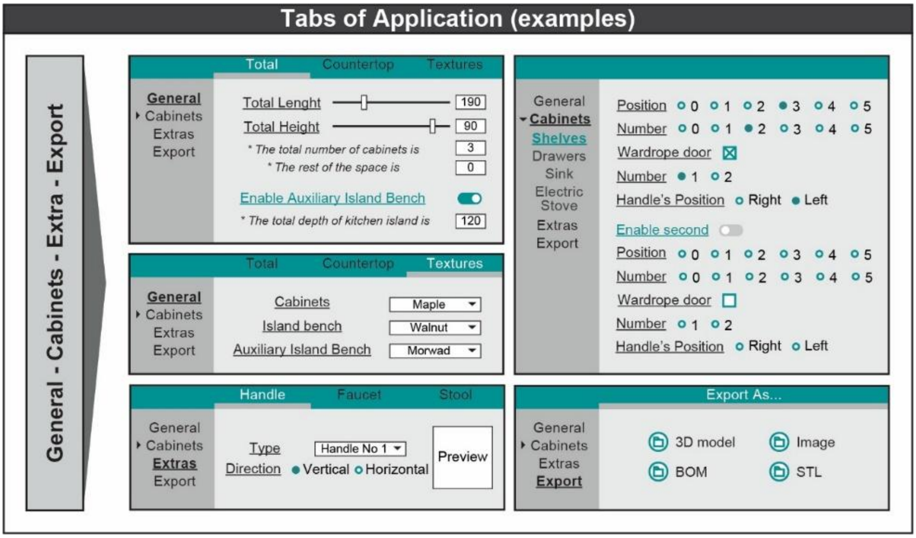


Figure 3: Examples of the tabbed interface (General, Cabinets, Extra, Export).

### 2.1.3 Structure of kitchen island

Regarding the basic design of the cabinets, components such as Slider, GhPython Script, Point, Line, Extrude, Offset, Loft, Move to Point, End Points, Area, List Item, Deconstruct Brep, Bounding Box, Plane, Contour, Flow, Rotate, Subtraction, Multiplication and Addition were used. The second sub-algorithm (cluster) is responsible for placing each cabinet in the corresponding position defined by the user through the application.

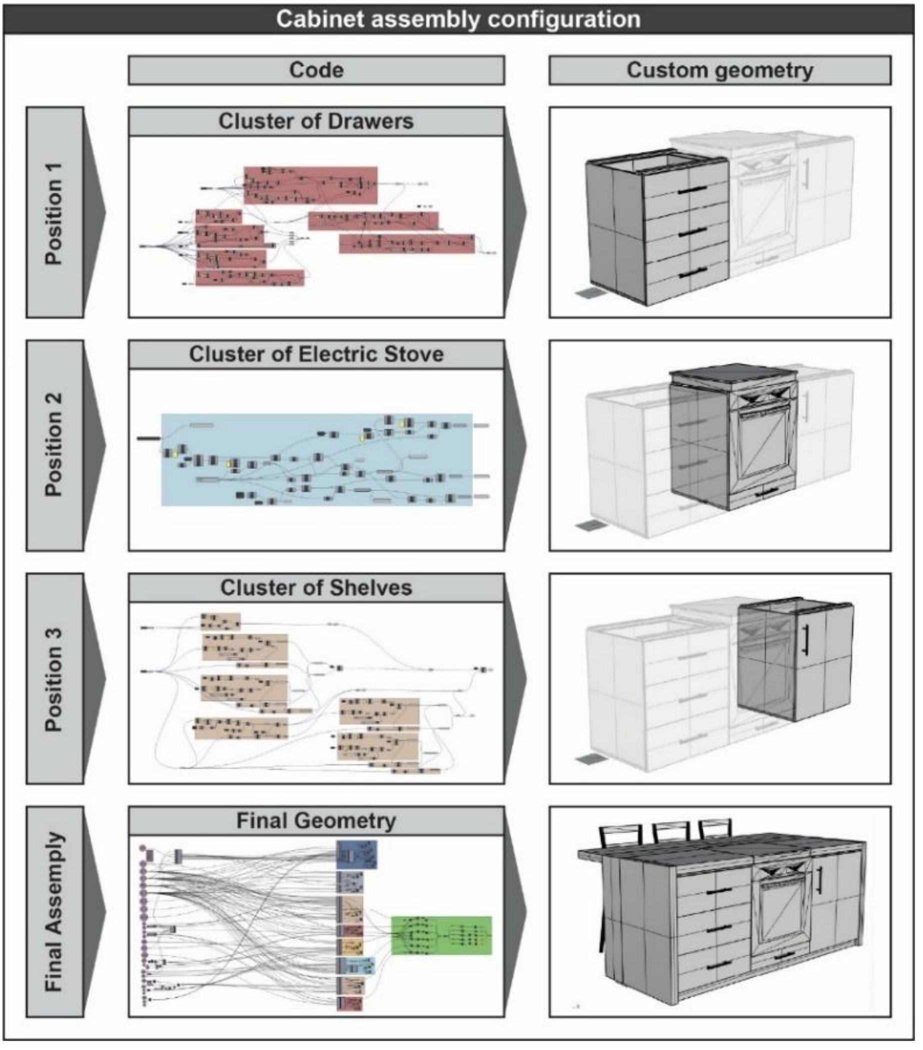



Figure 4: Basic geometry formed by combining cabinets; finalized with added elements via visual programming.

Additional commands selected in this stage include Filter, Group, Series and Flip. As mentioned above, the total length of the island determines the number of cabinets that will be used. Figure 4 illustrates the correct way to place them in sequence, defining which individual part will be positioned first, then the next and finally the last. In this example, the user has selected a chest of drawers with three drawers, followed by an electric cooker with a hob and a drawer below it, while in the third position there is a single cabinet that opens with a righthand rotation axis.

The next sub-algorithm (cluster) is related to the remaining structure of the island. Through this code, the floor base on which the cabinets are placed is created, along with the final countertop of the island, which consists of the main work area and an auxiliary folding surface. To make the island composition even more complete, stool seats are placed on the back side. A series of commands were implemented for the design of these elements, including Slider, GhPython Script, Filter, Value List, Point, Line, Extrude, Offset, Loft, Evaluate Surface, Area, Mirror, List Item, Deconstruct Brep, Bounding Box, Addition, Subtraction and Multiplication. Once again, users can select their preferred seating options from a predefined list, ensuring consistency with the overall kitchen design.

## 3. RESULTS AND DISCUSSION

The next part of the algorithm involves the extraction of the product's technical details as document reports. The first one depicts the final form of the kitchen island in three dimensions, including its selected materials and textures.

The final photorealistic representation of the island model will help both the user to see his choice complete, and the manufacturer to know what will be asked to fabricate. Additionally, the manufacturer will be greatly assisted by the second document, which includes the number of components (BOM) required to properly assemble the final product. Figure 5 depicts the layout of the above pages.

At the same time, the automated export of results in image and PDF format, which include photorealistic images, BOM and STL files of the final kitchen island, contributes towards its correct fabrication by the manufacturer. In Figure 6, the photorealistic visualizations, which correspond to a final result through the proposed application, are presented in an organized manner.

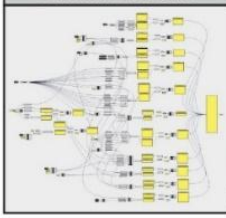
**Construction of the final Bill Of Materials**

**Process**

Material selection

Number of individual components

**Cluster of BOM**



**Bill Of Material (BOM)**

| ITEM | ITEM QTY | PART NUMBER | DESCRIPTION | MATERIAL |
|---|---|---|---|---|
| 01 | a | $x_1$ | Description $d_1$ | Material $m_1$ |
| 02 | b | $x_2$ | Description $d_2$ | Material $m_2$ |
| ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... |
| v | z | $x_v$ | Description $d_v$ | Material $m_v$ |

**Bill Of Material (BOM) of the purposed case study edition**

| ITEM | ITEM QTY | PART NUMBER | DESCRIPTION | MATERIAL | ITEM | ITEM QTY | PART NUMBER | DESCRIPTION | MATERIAL |
|---|---|---|---|---|---|---|---|---|---|
| 01 | LC | 3 | LOWER CABINET | MAPLE | 19 | FD2 | 0 | FRONT DRAWER_2 | MAPLE |
| 02 | CLS | 3 | CABINET LEFT SIDE | MAPLE | 20 | DLS2 | 0 | DRAWER LEFT SIDE_2 | MAPLE |
| 03 | CRS | 3 | CABINET RIGHT SIDE | MAPLE | 21 | DRS2 | 0 | DRAWER RIGHT SIDE_2 | MAPLE |
| 04 | BOC | 3 | BACK OF CABINET | MAPLE | 22 | BOD2 | 0 | BACK OF DRAWER_2 | MAPLE |
| 05 | BUP | 6 | CABINET UPPER PART | MAPLE | 23 | DUK | 1 | DRAWER OUTSIDE_K | MAPLE |
| 06 | LCE | 0 | LOWER CABINET_E | MAPLE | 24 | FDK | 1 | FRONT DRAWER_K | MAPLE |
| 07 | BOCE | 0 | BACK OF CABINET_E | MAPLE | 25 | DLSK | 1 | DRAWER LEFT SIDE_K | MAPLE |
| 08 | BOCE | 0 | CABINET UPPER PART_E | MAPLE | 26 | DRSK | 1 | DRAWER RIGHT SIDE_K | MAPLE |
| 09 | SCL | 1 | SINGLE CABINET LID | MAPLE | 27 | BODK | 1 | BACK OF DRAWER_K | MAPLE |
| 10 | DCL | 0 | DOUBLE CABINET LID | MAPLE | 28 | SH | 2 | SHELF | MAPLE |
| 11 | SCLE | 0 | SINGLE CABINET LID_E | MAPLE | 29 | EK | 1 | ELECTRIC KITCHEN | STEEL |
| 12 | DO1 | 3 | DRAWER OUTSIDE_1 | MAPLE | 30 | KEH | 1 | KITCHEN ELECTRIC HOB | CERAMIC |
| 13 | FD1 | 3 | FRONT DRAWER_1 | MAPLE | 31 | WB | 0 | SINK | STEEL |
| 14 | DLS1 | 3 | DRAWER LEFT SIDE_1 | MAPLE | 32 | FC | 0 | FAUCET | NICKEL |
| 15 | DRS1 | 3 | DRAWER RIGHT SIDE_1 | MAPLE | 33 | HD | 4 | HANDLE | BRASS |
| 16 | LD | 4 | LOWER DRAWER | MAPLE | 34 | CHG | 2 | CABINET HINGES | STEEL |
| 17 | BOD1 | 03 | BACK OF DRAWER_1 | MAPLE | 35 | SHS | 8 | SHELF SUPPORTS | PLASTIC |
| 18 | DO2 | 0 | DRAWER OUTSIDE_2 | MAPLE | 36 | DG | 8 | DRAWER GUIDE | STEEL |

Figure 5: Data extraction and automatic material list generation of the final kitchen island using programming

Using the application, users can design the kitchen island of their choice. The definition of the design characteristics through an organized list within the interface results in an algorithmic product design process. At the same time, the real-time digital representation of the three-dimensional model allows the user to visually control the outcome at each stage of the design. Figure 6 presents an example of the application in use. The resulting kitchen island model has been designed to meet the client’s requirements for functionality, ergonomics and aesthetics. The direct customization of the model highlights the advantages of this design method, which offers a wide range of options while maintaining the uniqueness of the final result. By defining the necessary parameters, the geometry and composition of the furniture are formed. The overall dimensions (length, depth and height) of the kitchen island, the dimensions of its individual parts, the components required for assembly and operation, and the material selections for the surfaces collectively determine the final configuration of the island.

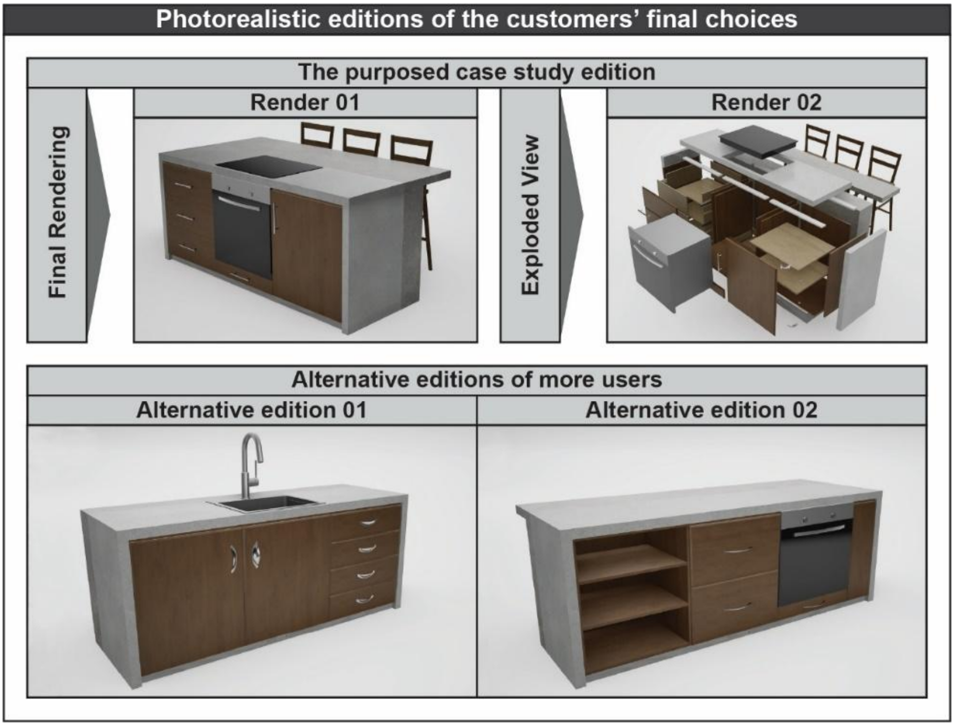



Figure 6: Rendered kitchen islands with individual components and user-generated designs based on final choices.

Once the design has been finalized, the user can export the kitchen island model in various formats beyond CAD, including a photorealistic rendering, an STL 3D model and a Bill of Materials (BOM). Finally, Figure 6 presents examples from users who tested the application and achieved satisfying results. Through this parametric tool, customized kitchen island compositions were created according to their needs, demonstrating the flexibility and effectiveness of product parametrization.

### 3.1 Design Efficiency and Digital Validation

The proposed framework achieves a high level of automation by consolidating design logic within a single parametric system, allowing multiple kitchen island configurations to be generated from a limited set of user-defined parameters. Users configure dimensions, modular components, and accessories through an interactive application, while the system updates the three-dimensional geometry and design data in real time. This approach reduces repetitive modeling tasks and ensures consistency across customized product variants. Manufacturing oriented outputs, including 2D technical drawings, Bill of Materials (BOM), STL files, and photorealistic renderings, are generated automatically from the parametric model, supporting accurate preparation for fabrication. The framework has been validated through digital and computational means within a CAD environment, demonstrating reliable generation of consistent design and manufacturing outputs across multiple configurations. Although physical prototyping and industrial testing were not conducted within the scope of this study, the results confirm the robustness of the proposed digital workflow for mass-customizable furniture design and advanced manufacturing applications.

### 3.2 Quantitative Evaluation of Design Efficiency

To further examine the efficiency of the proposed framework, a comparative evaluation was conducted between conventional CAD workflows and the proposed parametric approach, focusing on design time, error rate, and iteration efficiency. The evaluation was conducted across multiple design configurations under stable modeling conditions to ensure comparability between workflows.

The results show that the parametric system significantly reduces design time, since multiple configurations can be generated by simply modifying input parameters, without rebuilding the model. In contrast, conventional workflows require manual remodeling for each new variation. More specifically, the initial setup time is reduced from approximately 120 minutes in conventional workflows to around 35 minutes using the parametric system, while design modifications decrease from about 60 minutes to approximately 10 minutes.

Table 1: Quantitative comparison of key performance metrics between conventional CAD and the proposed parametric approach.

| Metric | Conventional CAD | Parametric | Improvement |
|---|---|---|---|
| *Initial setup time (min)* | *120* | *35* | *−70.8%* |
| *Modification time (min)* | *60* | *10* | *−83.3%* |
| *Dimensional errors (%)* | *7.5* | *0.8* | *−89.3%* |
| *Documentation errors (%)* | *6.0* | *0.5* | *−91.7%* |
| *Design variants per hour* | *2* | *15* | *+650%* |

In addition, the automatic generation of technical drawings, Bills of Materials (BOM), and STL files helps reduce human error and improve consistency across different design alternatives. Error rates were evaluated through inspection of generated design outputs across multiple configurations, considering dimensional accuracy and consistency between 3D models and technical drawings. As illustrated in Figure 7, error rates are significantly improved, with dimensional inconsistencies decreasing from approximately 7.5% to around 0.8% and documentation-related errors reduced from about 6% to approximately 0.5%, due to the automated and synchronized generation of geometry and outputs. This reduction is primarily attributed to the elimination of manual modeling and documentation steps, which are typically prone to human error in conventional workflows. By ensuring that all design representations are derived directly from a unified parametric model, the proposed framework minimizes discrepancies between the 3D geometry and the corresponding technical documentation.

From a productivity point of view, the framework supports rapid iteration and the evaluation of multiple design scenarios within a single environment. The parametric approach enables the generation of approximately 15 design variants per hour, compared to around 2 variants in conventional workflows, thereby improving decision-making efficiency. While the evaluation is based on digital validation within a CAD environment, the results highlight the potential of the proposed system to improve design efficiency and support advanced manufacturing workflows. Overall, the proposed approach demonstrates clear and consistent improvements in efficiency, reliability, and design flexibility compared to conventional CAD workflows.

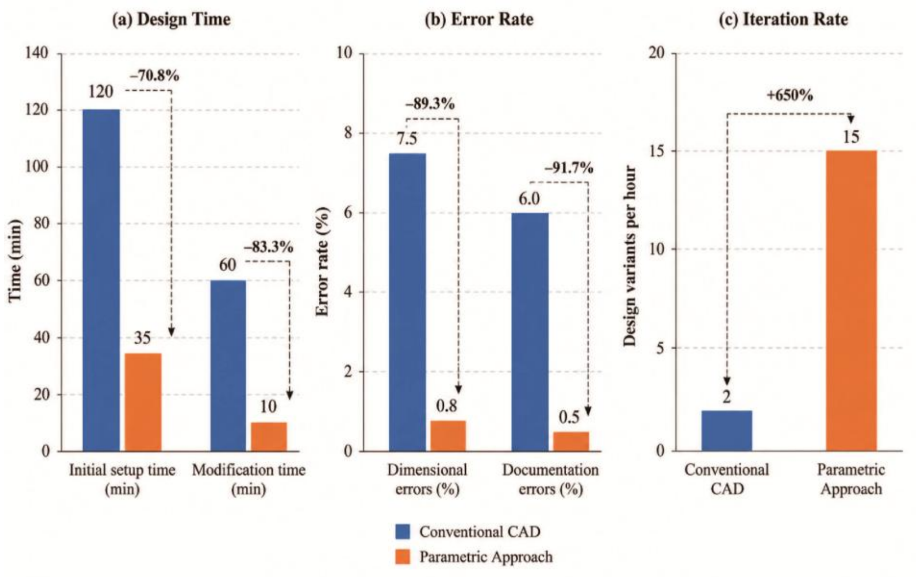



Figure 7: Comparison between conventional CAD and parametric workflows: (a) design time, (b) error rate, and (c) iteration rate.

## 4.0 CONCLUSION

The present research aims to automate the creation of a kitchen island for domestic use based on personalized design. The proposed methodology focuses on user participation through the selections made within the developed application. Since the user plays a primary role in the design process, higher satisfaction with the result can be achieved, as individual functional and aesthetic preferences are directly incorporated into the design outcome. The application is based on the principles of algorithmic product design, utilizing a parametric framework to generate the three-dimensional model of the kitchen island, along with complementary outputs such as photorealistic renderings and a Bill of Materials (BOM). The diversity in composition and the resulting design alternatives are achieved through interactive elements such as buttons, sliders, indicators, and switches, allowing continuous exploration of different configurations. Real-time visualization of the kitchen island, combined with user-defined parameters, supports informed decision-making and improves the overall design experience. At the same time, the automated export of manufacturing-related files, including material lists and component specifications, contributes to accurate and efficient preparation for production. Beyond user-centered benefits, the proposed system also supports reductions in repetitive design tasks and overall development time within industrial workflows.

The validation of the proposed framework in this study is primarily based on digital and computational evaluation within a CAD environment. The consistent automated generation of three-dimensional models, technical drawings, Bill of Materials (BOM), and fabrication-ready STL files demonstrate the reliability and applicability of the proposed workflow at the design and pre-manufacturing stage. At this stage, the proposed framework has been evaluated through digital and computational means. Physical prototyping and industrial validation, such as CNC manufacturing or collaboration with production partners, constitute a natural extension of the present work and are planned as part of future research. Future research will extend the proposed framework toward physical fabrication and industrial testing, while the present study contributes an integrated algorithmic methodology that supports mass customization within a unified digital design to fabrication workflow.

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## AUTHOR CONTRIBUTIONS

L. Firtikiadis; A. Manavis: Conceptualization, Methodology, Software, Writing – Original Draft Preparation; A. Manavis; P. Kyratsis; N. Efkolidis: Data Curation, Visualization, Validation; P. Kyratsis; N. Efkolidis: Supervision, Resources, Writing – Reviewing and Editing.

## CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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