



DESIGN OF CHARCOAL BARBEQUE GRILL

Lappeenranta–Lahti University of Technology LUT

Bachelor's Degree Programme in Mechanical Engineering, Bachelor's thesis

2026

Rose Brennan

Examiner(s): University Lecturer, D.Sc. (Tech), Changyang Li

Associate Professor, Hua Yang

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

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This thesis presents the design process of a charcoal barbeque grill that integrates a requirement-driven approach to develop a system optimized for Northern European operational conditions. The goal is to implement a structure that is reliable, easy to assemble, and convenient to transport, providing compatibility with outdoor operations. A modular approach is adopted to balance system simplification and ease manufacturing prospects without compromising functionality. The design assembly is modelled using computer-aided design (CAD) software and simulated in a finite element analysis (FEA) software environment under realistic operational conditions to assess structural stability. The optimized grill configuration demonstrates a modular design founded on user requirements and Design for Manufacture and Assembly (DFMA) principles that offers a solution which balances design efficiency, manufacturability, and practicality.

ACKNOWLEDGEMENTS

To my dad, Steve Brennan.

Your wonderful outlook on life and endless support has allowed me to experience miraculous things. I am forever grateful for the beautiful life you have given me.

Over time, you have consistently motivated me with your wisdom. The most important of which is the very first one I remember is a promise we made, "Don't ever let anyone tell you what you can or cannot do, including me or yourself. Always follow what you want in life that makes you happy, and you can do more than you can dream of."

SYMBOLS AND ABBREVIATIONS

Abbreviations

CAD	Computer-Aided Design
DFMA	Design for Manufacture and Assembly
FEA	Finite Element Analysis
mm	Millimeter
MPa	Megapascal
N/m	Newton per Square Meter

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DECLARATIONS

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The originality of this thesis has been reviewed with the Turnitin similarity checking service.

AI usage

The author of this thesis, Rose Brennan, did not use any AI tools during the preparation of the thesis.

1 Introduction

European society is driven by social gatherings and a dynamic lifestyle, with the preparation of traditional food playing a vital role in culture. Outdoor grilling is a popular practice in European communities, often in communal spaces such as parks, forests, and lakesides (Leer, 2023).

Currently available outdoor cooking systems raise concerns in key areas of user practicality such as portability, functionality, and structural performance. Design inefficiencies also tie into rising concerns regarding sustainability due to excess material usage and combustion inefficiency leading to fuel waste.

This research identifies key design issues with market-available grills and addresses them through optimized design development. The design process is guided by the application of Design for Manufacture and Assembly (DFMA) principles and defined research objectives.

1.1 Background

Many grills currently available on the European market are not designed to facilitate modular assembly, with grills often being large, difficult to transport, or containing overly complex components. These limitations often discourage the use of grills, especially with harsh weather conditions during cold seasons (Khairunnisa et al., 2025).

1.2 Sustainability

The inefficiency of current grill designs introduces sustainability concerns such as unnecessary fuel consumption, excess material usage, and a reduced product lifespan. Furthermore, low quality airflow control designs result in inefficient combustion, increasing fuel consumption, and reducing energy efficiency. These issues are reflected across the manufacturing, usage, and maintenance of the current market-available grills.

Manufacturing efforts are convoluted by intricate, specialized designs, contributing to increased costs, production efforts, and material waste. Additionally, many grill designs

rely on unique or non-standardized components which limit repairability and contribute to product disposal. (Mencarelli et al., 2023).

These issues present the need for a modular grill designed with a framework of material usage reduction and system efficiency. The proposed design approach incorporates a balance of stability, portability, thermal functionality, and manufacturability to enhance sustainability and functional performance.

1.3 The Design & Use of Barbecue Grill

The design and use of barbecue grills vary regionally, with system components reflecting food culture, climate, and cooking routines. In Northern Europe, grilling practices typically include the preparation of fish, vegetables, and meat cuts.

Barbeque grills offer ideal preparation characteristics for Northern European dishes, such as the functionality of a grill cook space in cold climates, ability to control flavor aromas and high temperature with short cooking durations. Furthermore, food involved in Northern European grilling is typically minimally processed, with charcoal heat generation allowing for enhanced flavor and aroma development (Leer, 2016).



Figure 1 European-Style Meat and Vegetables on a Charcoal Barbecue Grill (Perrett, 2025)

1.4 Research Gap and Motivation

Previous research regarding grill system design evaluated features such as airflow control, thermal performance, and combustion efficiency. While these analyses offer valuable insights into grill performance, they do not balance findings into an optimized system (Hayyat et al., 2024).

The optimized grill design relies on the conclusions of previous research, with consideration of Northern European regional food, cooking methods, and environmental conditions. This involves eliminating non-essential components, prioritizing combustion efficiency and temperature control, along with consideration of usability and manufacturability into the design.

1.5 Research Problem & Questions

The development of a modular charcoal grill intended for the Northern European market is approached with an analytical and iterative perspective, driven by requirements analysis of functionality, manufacturability, and portability. The grill system is organized into three modules, to form an architecture which optimizes key functional components. DFMA principles are prioritized throughout the process, to minimize part count and simplify the assembly process.

The identified challenges of market-available grill systems define the following research questions:

1. How can DFMA principles be applied to reduce part quantity and simplify assembly?
2. How can the structural design of the grill remain reliable with minimized system complexity?
3. How can airflow and heat monitoring remain controlled with minimal system complexity?

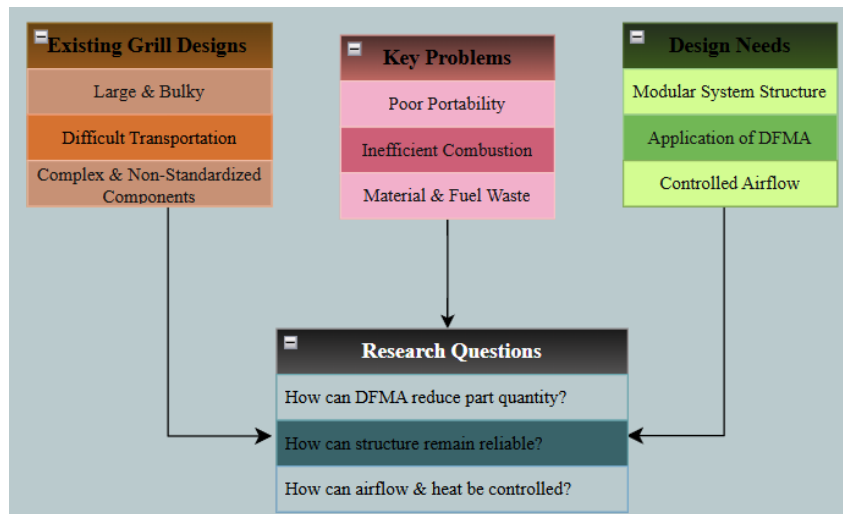


Figure 2 Research Questions Defined in Relation to Topical Issues

Figure 2 demonstrates the issues in existing grill designs, the resulting key problems, identified design needs, and their relation to the research questions. The research questions encourage a design approach progressing from the initial concept of development to CAD modelling, testing, and refining to achieve a product design optimized for intended consumers. The research objective is to develop a modular, portable, and manufacturable charcoal barbecue grill, optimized for use in the European market, balancing simplicity, manufacturability, and production efficiency.

2 Methods

The methodology of the development of a modular charcoal grill relied on an analytical and iterative design process. The process began with an analysis of the requirements of the grill system to align with Northern European living conditions and research objectives. The system architecture was conceptualized according to the identified requirements, material choices, and component selection. The design was modelled using CAD software, and structural integrity was evaluated in a FEA environment.

DFMA principles were considered at each stage of the methodology to establish a structured design process that directly addresses the research questions and design requirements. Each stage in the design process involved justification for design choices, and the design was refined to ensure functional performance and prioritize design objectives.

2.1 Requirements Analysis

The design of the grill was based on requirements derived from consumer needs related to functionality, structural stability, portability, and manufacturability, supported through literature review and market-available grill design analysis. The requirements of the system formulation were directed by the objectives and constraints which guided the architecture development to uphold usability in Northern Europe living conditions.

Crucial functional requirements of the grill include controlled airflow and temperature to achieve effective cooking capabilities. The grill development facilitated a cooking surface design which accommodates common Northern European food such as fish, vegetables, and meat, all requiring controllable and steady heat for preparation. Adequate heat generation and retention, as well as user airflow regulation to control combustion was balanced in the system to ensure thorough cooking (Global Alliance for Clean Cookstoves, n.d.).

Structural requirements of the grill configuration establish safety and stability during user operation. Harsh weather conditions, uneven outdoor surfaces, and varying loading conditions on the cooking surface were considered to establish a design which remains stable and efficiently operable to ensure user safety. Structural components such as a stable support

frame, fixed cooking grate, and a reinforced grill body contributed to ensuring grill structural stability. (Bakeer, 2022)

Portability requirements were considered to ease transportation and storage of the grill, especially in consideration of the challenging Northern European climate. The structural arrangement was prioritized to be lightweight, compact, and sturdy, providing smooth transportation in outdoor settings. Furthermore, components which facilitate movement, namely handles and wheels for eased user manipulation capabilities, were vital system inclusions. (CEN Standards, 2024)

Manufacturability requirements were considered through the application of DFMA principles. Considerations included component quantity minimization, reliance on simple and cost-effective manufacturing processes, and a reduced assembly complexity. These considerations were carried out through the reduction of nonessential features and standardization of components to reduce cost and enhance production efficiency (Goldense, 2022).

2.2 System Architecture Development

A modular design approach was adopted for the system architecture development, dividing the grill into individual units based on function. This approach allowed subsystem development to concentrate on specific requirements, with the formation of an effective final system through integration of each module.

The architecture development divided the system into three primary modules: the cooking module, the charcoal & airflow module, and the structural & portability module. The cooking module consists of the grill elements which contain the food and deliver heat transfer to the cooking surface. The charcoal & airflow module contains fuel, controls combustion, and facilitates heat transfer to the cooking module through the air intake and exhaust. The structural & portability module supports the physical structure of the system, allows for transportation, and supports general operation for users (Gumino et al., 2020).

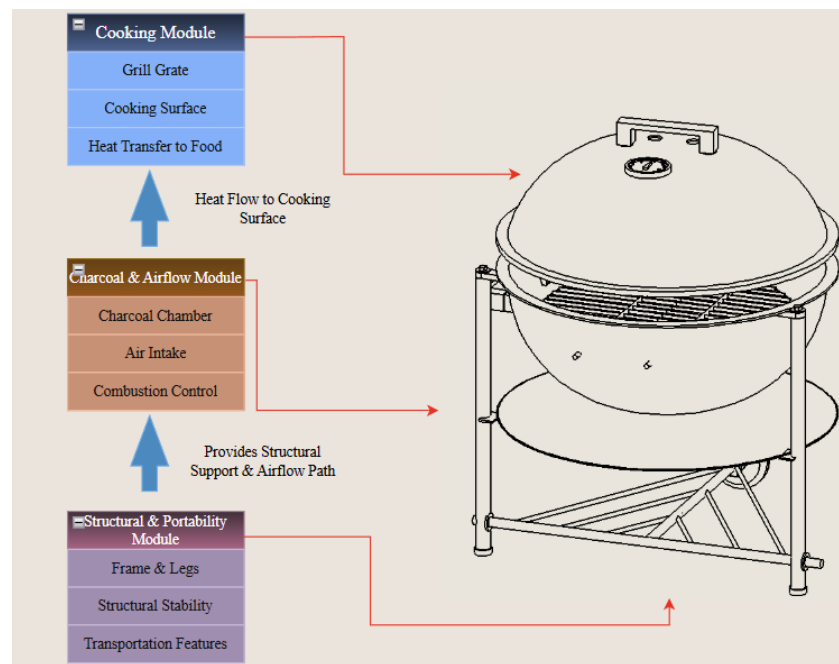


Figure 3 Modular System Architecture Coherence

Figure 3 displays the system architecture with context to the intended congruence of the separate modules. Each module incorporates components which conform to coordinate an assigned purpose that enables system functionality.

The modular focus of the grill system was supported by DFMA principles through a concentration on components which are essential for operation yet avoid unnecessary complexity. Furthermore, modular organization allowed for functional classification of parts, therefore allowing for total part count to be minimized and assembly simplification. The development of a modular system architecture allowed for a design process which solidified a grill configuration which aligns with the desired qualities defined in the research objectives. (Ulrich et al., 2020)

2.3 Component Selection and Material Considerations

A hybrid component configuration of market-available parts, as well as customized elements, was implemented. Market available components were selected for grill components which are widely manufactured, such as the grill grate and sensor, as they provide reliable performance results with a low-cost. Custom components were selected for

elements which do not have market available options that effectively align with system objectives.

The selection of material properties for the components was driven by ISO standards as well as operational conditions of the grill considering heat and harsh environmental conditions. The material must be able to preserve the system's component integrity against rain, wind, snow, and prolonged periods of outdoor exposure. Operational requirements guided the decision to select a material composition for the internal components of stainless steel due to its heat and corrosion resistance properties (Habib et al., 2011).

Structural components were preferred to have a material composition of stainless steel due to its lightweight yet durable properties, with further improved heat and environmental durability properties enhanced with a ceramic-based dialuminium trioxide coating (Jose et.al, 2025). The grill body and lid are the largest components within the system; therefore, a specialized material choice of carbon steel was deemed optimal to reduce the assembly weight to accommodate portability (AZO Materials, 2012). A porcelain coating accommodates the lower corrosion resistance properties of carbon steel to adequately preserve the structure in outdoor environments (Russo, 2021). Further materials did not contribute to a significant portion of the system's material composition consideration; however sustainable and recyclable solutions such as wood and rubber were opted to accommodate components not optimally supported by stainless steel.

2.4 CAD Modelling

The grill was fabricated with computer-aided design (CAD) software to visualize the design concept. Furthermore, the CAD environment allowed for individual component assessment and alterations based on simulated system compatibility.

The modelling process involved designing a model of the chosen pre-existing components and then developing the customized elements with consideration of design requirements. The modelled components were then configured into the respective modules, and integrated into a final design assembly, visualizing the grill system concept. Drawings were made from both individual parts as well as assemblies to visualize component specifications to aid manufacturability.

2.5 Analysis and Evaluation

The structural performance of the grill was evaluated using a finite element analysis (FEA) simulation software, employing static structural studies. The model included a representation of ground-contact support conditions, evaluation of the impact of gravity on the structure components, and assessment of the payload capacity of the cooking surface. The focus of the analysis aimed to provide verification of the structural stability of the grill structure when subjected to expected loads, to avoid excessive stress concentrations. The results of the analysis were vital in assessing the system structural reliability to ensure effective operational capabilities with reference to the simplified structure (Chen et al., 2022).

2.5.1 Model Assumptions

The FEA model sought to replicate the expected operational conditions of the grill. Model assumptions included homogenous and isotropic material properties, with a primary material assignment of stainless steel 1.4301 to the assembly. These premises reflected simplified conditions of the design yet enabled practical evaluation of the systems' structural performance.

The simulation did not consider environmental influences such as wind, snow, rain, or further complexities due to limited software capabilities. The analysis considered the assembly material configuration to be uniform, consistent with the majority of system component composure, however not fully parallel to the outlined material configuration of all system components.

2.5.2 Gravitational Analysis Simulation Configuration

Numerous conditions were applied to the assembly to simulate real operating conditions, including fixed supports, external loadings, and gravitational forces. Each of these assumptions were applied with a goal to validate structural performance while avoiding unnecessary complexity.

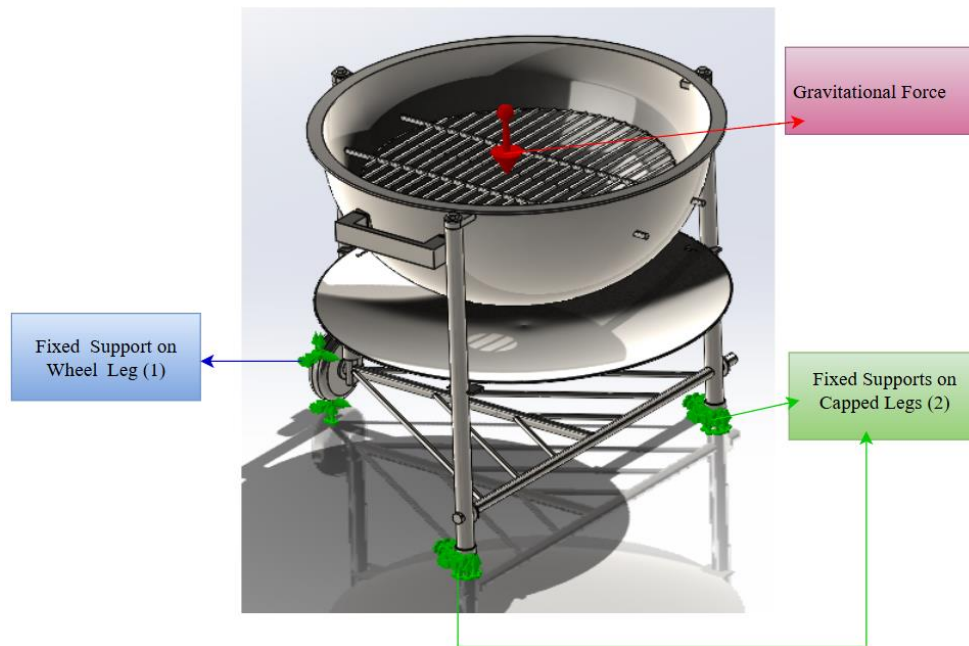


Figure 4 Locations of the Fixed Support Placements in the Simulation Environment

Figure 4 demonstrates the placement of fixed supports at the points of contact between the ground and the bottom surface points of the grill. Specifically, at the bottom surfaces of the legs, and the wheel outer circumference. These points were designed to remain stable during operation and provide support to the grill structure from the ground.

2.5.3 Distributed Load Simulation Configuration

An additional study was performed with twin model assumptions and conditions outlined in the gravitational analysis study, with an addition of a distributed force on the centrality of the cooking grate. Figure 5 illustrates the placement of an expected maximum distributed load of 50 N (Approximately 5kg) to the surface of the cooking grate to simulate the effects of weight from food or cooking equipment during operation.

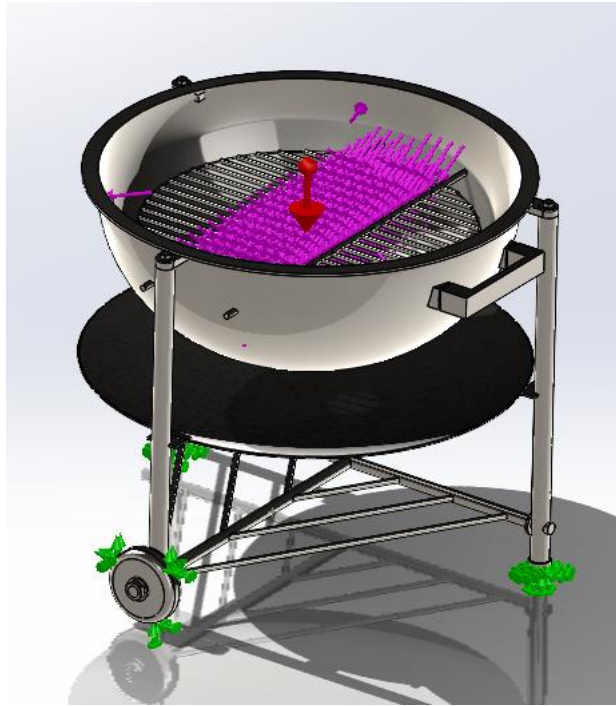


Figure 5 Grill in Simulation Environment with Distributed Load on Grate Surface

2.6 Design Refinement

The final design of the grill system was developed through an iterative refinement process based on the outcomes of DFMA evaluation, CAD modelling, and structural analysis. Design improvements were implemented throughout the system development process, to reduce complexity, elevate functionality, and align with the defined objectives and DFMA principles.

A crucial concentration on the charcoal & airflow module allowed for significant system simplification. A consideration of optimized airflow strategies and requirements fostered the development of an integrated design system subject to natural convection and heat flow patterns. This enhancement eliminated the need for specialized or complex components to streamline combustion processes.

The structural & portability module was improved through considerations of weight and component modifications to ease handling and practical use. The mass was designed to be distributed throughout the base of the structure for structural stability assurance.

Furthermore, the material composition was prioritized to contribute to assembly weight reduction, especially in consideration that the module carries a majority of the part count.

CAD modelling offered perspective on system enhancement through the visualization of the final assembly. The assembly revealed modification initiatives which eased component coordination.

The structure was refined for enhanced simplification whilst upholding simulated stability and load requirements of the system. The system refinement process maintained the goal of a simplified system without compromising the reliability of the structure, performance, or manufacturability (Globell et al., 2013).

3 Results

The results section demonstrates the developed grill design and detailed configuration outcomes of the modular composition. The CAD model was evaluated using FEA software to simulate the design's congruency with the outlined system objectives under realistic operational conditions.

3.1 Final Grill Design

The concluded design of the modular charcoal grill implemented the defined characteristics of a modular system that integrates stability, airflow, and simplified assembly. The configuration of the three-module architecture coordinated the separate functions while maintaining the integration of each module into a unified system. Figure 6, a rendering of the CAD-designed components assembly demonstrates a realistic representation of the final grill design.



Figure 6 CAD Render of Grill Assembly in a Conventional Northern European Environment

3.2 System Architecture Results

The modular configuration of the system architecture was implemented through three units: the cooking module, the charcoal & airflow module, and the structural & portability module. The performance of the grill is supported by the function of each subsystem, with the separation of these modules enabling independent development and optimization of the system architecture.

3.2.1 Cooking Module

A thermocouple probe Type K temperature sensor allows for temperature monitoring to accommodate the preparation of food items. The component has temperature sensing capabilities ranging from 0-1100 °C, which enables monitoring within the expected operational temperature range. Furthermore, the sensor is composed of polytetrafluorethylene metal, compatible with the conditions of an operational grill system environment (NIST, 2024). The probe was strategically placed on the upper, inner surface of the grill lid to effectively measure the average temperature while avoiding direct flame, ash, or food contact.

The cooking grate is a standard market element that is fully removable to facilitate replacement, cleaning, or maintenance. The grate is composed of stainless steel 1.4301 due to its high heat and corrosion resistance, and compatibility with food hygiene (Zaffora et al., 2021). The grate spacing is narrow enough to prevent food from falling through yet allows for airflow and heat transfer from charcoal.

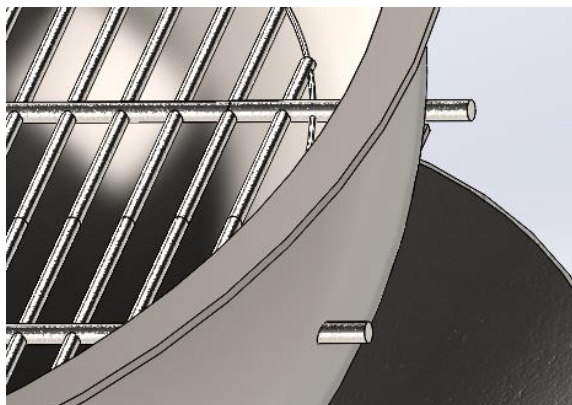


Figure 7 Integrated Grate Mounting Mechanism

Figure 7 demonstrates the grate interface with the grill body through circular openings on the side of the grill body, in which extruded bars are inserted, and the grate component is supported by the body.

3.2.2 Structural & Portability Module

The structural & portability module provides system organization and support to any external loads placed on the cooking surface during operation. The legs and frame provide stability and allow the system to be easily maneuverable on outdoor terrain through its lightweight material composition and wheel.

The main supporting structural elements are the legs, which are the contact points between the ground and the grill configuration. Two of the legs have capped ends which enable stabilized mounting on outdoor surfaces. One of the legs houses a wheel which facilitates movement. The legs all carry a support plate extrusion at mid length to distribute the load of the centrally situated ash collection tray.



Figure 8 Ground-Level Configuration of Grill System

Figure 8 demonstrates the design of leg reinforcement by a welded support bracket, which is inserted into circular openings near the base of the legs and fastened using standardized elements. The bracket is composed of steel bars with triangular geometry to efficiently distribute structural stress in reference to the three-leg layout (Vivek et al., 2016). The support bracket provides system reinforcement and alignment. The positioning of the support bracket near the base of the configuration was intended for optimal structural insurance under adverse terrain manipulation.

The grill body and lid contribute to the largest system components by volume and house the vital internal components necessary for combustion and cooking. Both elements contain integrated system features which simplify the final assembly, namely strategic openings to support efficient airflow. Figures 9 and 10 demonstrate the strategically located openings on the grill structure which enable airflow control and contributed to a significant reduction in components in the other primary modules.



Figure 9 Grill Bottom Lid from Underside Perspective



Figure 10 View of Grill at the Upper-Region of Architecture

The body of the grill is supported by mounting brackets fastened at the uppermost points of the legs, demonstrated in figure 11. The lid rests on the flat rim of the grill body.

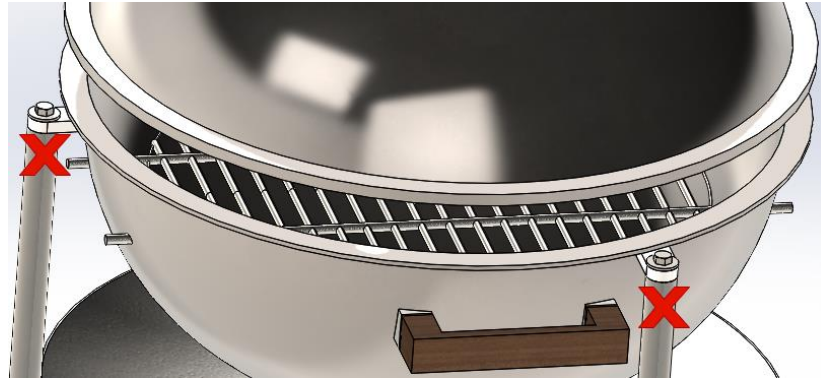


Figure 11 Body view With Marked Lid Supports

Additionally, the module features wooden handles located on the grill lid and the side of the grill, allowing for simplified user manipulation of the grill during transportation or operation. The placing of a handle parallel to the wheel allows for consistent pushing or pulling motion of the grill during transportation.

3.2.3 Charcoal & Airflow Module

The charcoal & airflow module regulates system combustion and contains the fuel chamber and ash collection components. Air intake is controlled through openings on the bottom surface of the grill's body, and the exhaust pathways located on summit of the grill lid.

An ash collection tray was situated underneath the grill body to collect any debris which is expelled during operation. The component is situated between the legs supported by plate extrusions on the legs, displayed in figure 12.

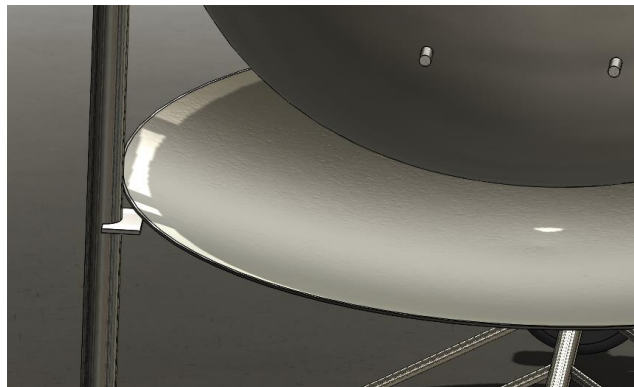


Figure 12 Close-Range View of Support Extrusions

The extrusions allow for stable reinforcement of the tray while maintaining smooth removal of the component as it is not permanently joined to the support. Furthermore, the eased removability enhances cleaning, maintenance, and replacement capabilities.

3.2.4 System Assembly

The final system assembly was composed of the outlined primary modules and fastened using standardized bolts and nuts, demonstrated in figure 13. Standardized fasteners were used across all joint connections, contributing to the reduction in component variability and complexity. The design achieved a total structural weight of approximately 12 kilograms, accommodating single-person handling without undermining stability in a range of environments (ISO, 2021)

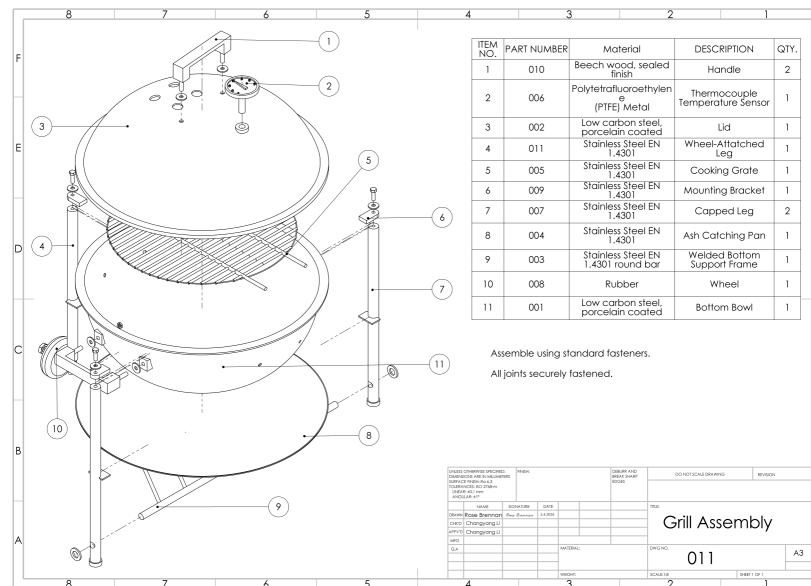


Figure 13 CAD Drawing of Grill Assembly

3.3 Finite Element Analysis

The structural performance of the grill assembly was evaluated in a static structural FEA simulation. The analysis environment simulated real-world conditions in which a user would operate the grill, including gravitational forces acting on the system components, ground

contact supports, and a distributed load on the cooking surface. The analysis validated the structural stability design considerations through evaluation of stress concentrations within the structure.

3.3.1 Gravitational Analysis

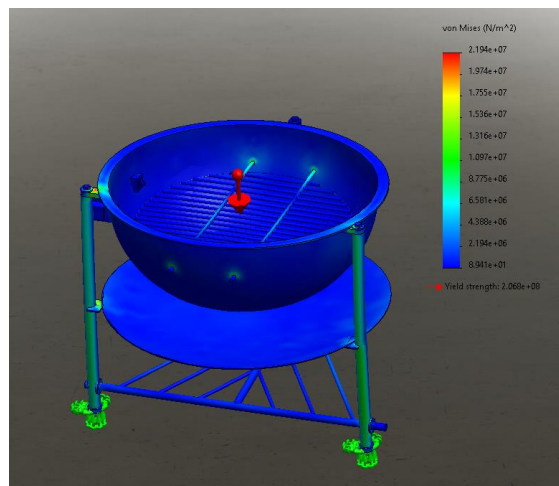


Figure 14 Von Mises Stress Results of Gravitational Analysis

Figure 14 shows the stress distribution within the system structure under the simulated effects of gravity. The color gradient displays the magnitude of stress in the impacted region, with warm colors representing points of higher stress, and cooler colors depicting minimal or void stress concentration.

The study demonstrated minimal structural stress with gravitational forces acting on system components. The simulation revealed the largest stress concentration located on a support bracket which provides support to the grill bowl and loadings on the cooking surface. This locality bears a von Mises Stress of approximately 2.194×10^7 N/m², or 21.94 MPa.

Simulated results presented the majority of the structure carrying minimal stress concentrations, reflected in the cool toned palette of the assembly model. Additionally, the simulation defined a system yield strength of 206.8 MPa.

3.3.2 Distributed Load Analysis

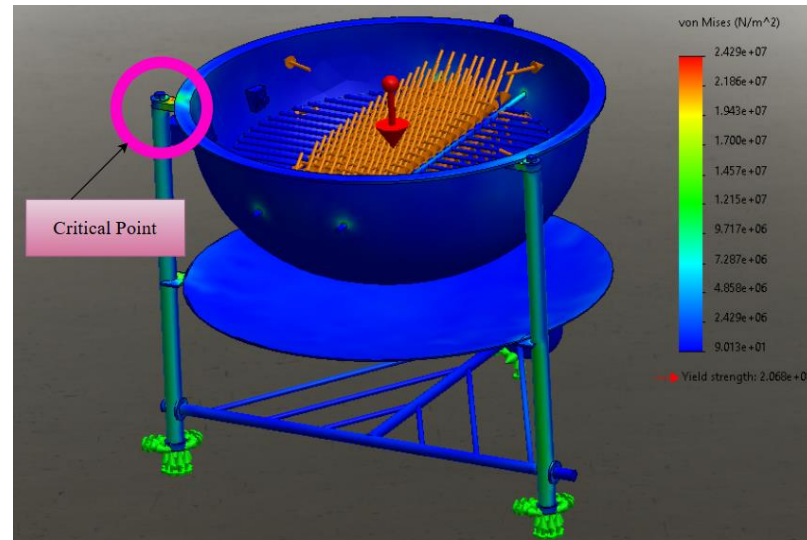


Figure 15 Von Mises Stress Results of Distributed Load Analysis

Figure 15 shows the stress distribution within the system structure under the simulated effects of gravity and an additional distributed force acting along the center of the cooking grate. The distribution of stress had no abrupt concentrations and followed a near continuous gradient.

The simulation demonstrated the largest stress concentration occurrence at the same location as identified in the gravitational simulation, with a maximum von Mises Stress of 24.29 MPa. The support bracket was considered the critical point of stress in the structure due to its vital role in supporting key system components and any applied loads.

The simulation presented negligible stress throughout most of the structure, and a yield strength of 206.8 MPa. Minimum stress concentrations were located near the base and throughout the structural frame. These results verified that the grill structure remains reliable under gravitational forces and applied loads.

3.4 Thermal & Airflow Operation

The combustion system was organized to remain fully functional with substantial system simplification. Figure 16 demonstrates the integration of strategic positioning of intake and exhaust openings into the grill structure to regulate airflow control.

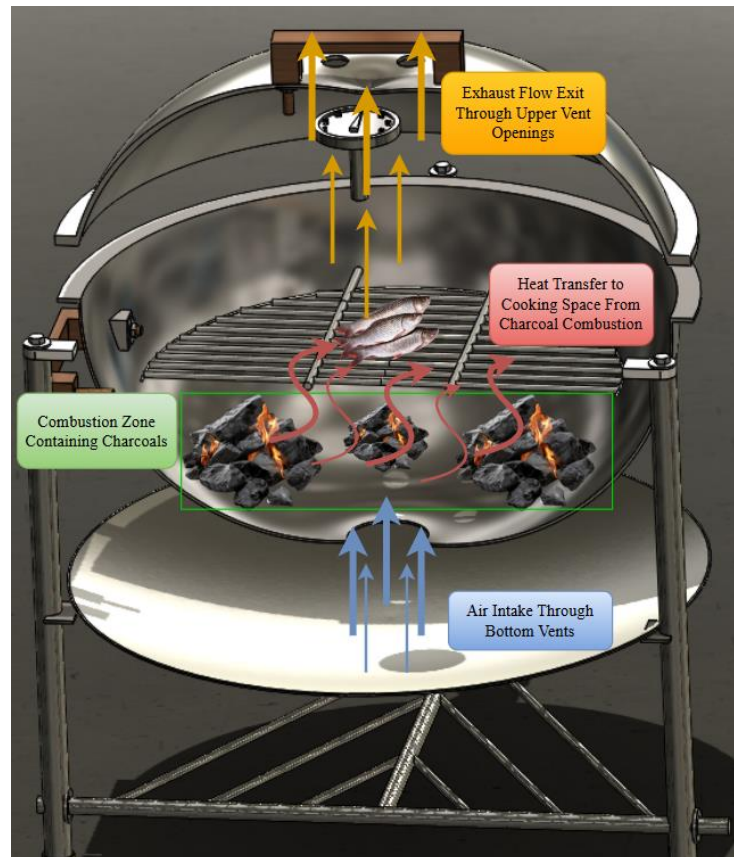


Figure 16 Integrated Airflow Pathway Configuration

This topology established an organic airflow path design driven by convection effects, with oxygen entering through the combustion chamber, and resultant hot gases emitted through the openings on the lid. The airflow is facilitated through natural convection from temperature disparities between the hot combustion gas and cool ambient air. The internal temperature increases proportional to charcoal combustion, inducing a pressure difference between the internal system and the outside environment, which stimulates a regulated airflow of oxygen-rich air through the intake (Sahoo et al., 2025). Further mechanical regulation is not required to sustain combustion, balancing functional performance, and research objectives.

4 Analysis

The results reveal the final grill designs compliance with the research objectives of reduced complexity, structural reliability, and manufacturability. The DFMA framework was used to guide the design process and develop a grill design that provides a solution to the research questions.

Interpretation of the CAD model assembly static structural FEA simulation results along with analysis of key DFMA design choices are evaluated to validate system configuration decisions. Inspection of part reduction, assembly simplification, modularity, and manufacturability reveals the designs alignment with expected user operating conditions and design efficiency.

4.1 CAD Results

The assembly behavior was simulated in an FEA environment under gravitational forces and a distributed load along the cooking grate. The results display minimal system stress concentrations, concluding the grill design to perform effectively under expected operational conditions.

Both simulations display minimal stress concentrations throughout the structure, indicating a reliable structure under intended operational conditions. The critical point is uniform in the simulations, a support bracket near the top of the frame. The maximum stress concentrations in both simulations remained notably below the yield strength of stainless steel 1.4301 (approximately 206.8 MPa).

Further validation of the CAD results is extended through consideration of the structure's safety factor. The maximum stress is selected from the distributed load analysis due to it holding the higher magnitude from the performed simulations

$$Factor\ of\ Safety = \frac{Yield\ Stress}{Maximum\ Stress} \quad (1)$$

$$Factor\ of\ Safety = \frac{206.8\ MPa}{24.29\ MPa} \quad (2)$$

$$\text{Factor of Safety} \approx 8.5 \quad (3)$$

The safety factor calculation signifies that the grill structure design facilitates operation within safe mechanical design limits under the expected operational conditions. Furthermore, the high safety factor guards a substantial margin against material deformation or failure.

The load distribution is adequately controlled throughout the system structure to withstand the expected operating conditions. The results validate that the design simplification does not pose failure or deformation risks and support functional performance and design objectives.

4.2 Design for Manufacturing

The reliance on DFMA to guide design choices is reflected through the reduction of component quantity, assembly simplification, and manufacturability. These decisions were executed with the intention of developing a system composed of components which are reliable, manufacturable, and compatible with research objectives.

4.2.1 Reduction of Part Count

The implication of a DFMA strategy encouraged an enhanced analysis of system components, specifically in consideration of their design practicality and necessity. Features which are commonly composed of complicated, unstandardized components were simplified in a way to facilitate function with minimized parts. Major part reduction features include the elimination of specialized technical features, unnecessary structural elements, and complicated combustion system components. The focus on key components for system alignment with the research objectives resulted in a significant part-count reduction in the final design configuration.

The impact of component reduction is exemplified by a comparison between a popular market-available charcoal grill and the developed design. Figure 17 outlines key componential, structural, and configuration choices that highlight the influence of the DFMA strategy on the design configuration.

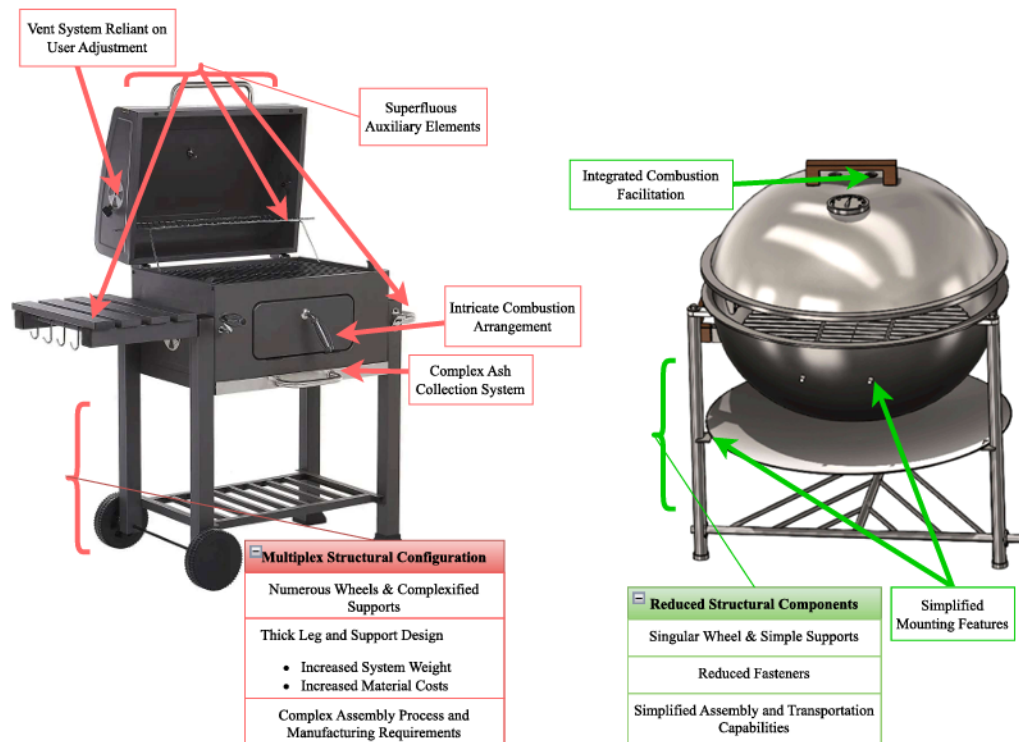


Figure 17 Key Design Contrasts of Market-Available Grill and Optimized Design

The contrast between the commercial grill and the outlined design highlights key advantages of component reduction. Furthermore, the comparison underlines the impact of reductions in component complexity, assembly requirements, and a simplified structure. The prioritization of part reduction aligns with DFMA through improved manufacturability, lower materials cost, and reduced assembly complexity.

4.2.2 Simplified Assembly

The reduction of system components yields a simplification of the system assembly, eliminating the need for specialized tools and fastening materials. An evaluation of individual modular organization reveals key system refinements which simplify manufacturing procedures.

The cooking module includes simplified features of an easily removable, singular cooking grate, and a simple temperature sensing element. The cooking grate allows for a reduction in production complexity due to its straightforward design and integrated mounting scheme,

avoiding excessive cooking components and lessening the quantity of mounting elements. Furthermore, the module presents a reduction of superfluous auxiliary features, with the sole component being a thermocouple temperature probe that does not rely on an outside power supply source for function. Simplification of the cooking module eliminates common grill elements that introduce manufacturing and assembly complexities.

The charcoal & airflow module offers simplified design properties through reduction of intake and exhaust components, and an adaptable ash collection system. Integration of airflow eliminates complex combustion components commonly found in grill designs, directly reducing assembly part count. The ash collection tray allows simplified assembly as the component is not fastened in place yet remains stable due to the strategic supports.

The structural & portability module introduces further simplicity through standardized fastening components, a reduced quantity of structural members, and a highly manufacturable material composition. The grill is supported by 3 legs and a straightforward welded support bracket which minimizes structural complexity while maintaining structural integrity. The module has a material composition of widespread materials involved mainly stainless steel 1.4301. Manufacturing processes of stainless steel 1.4301 such as forming, cutting, and welding have been highly optimized in production industries, easing manufacturing costs and supplier logistics. Additionally, integration of combustion elements and mounting features into the structure allows for a reduction in assembly complexity and maintenance efficiency.

4.2.3 DFMA Evaluation

The persistent application of DFMA from the initial to final stages of the grill design development yielded a framework in which the research questions could be addressed through specific design choices which manage market-available grill issues. Namely, grill design issues such as component complexity, portability challenges, and combustion issues are combatted through the application of DFMA to introduce design improvements that diminish inefficiencies and present realistic solutions to the research questions. Figure 18 illustrates how consistency of DFMA theory provided design solutions to resolve the research questions.

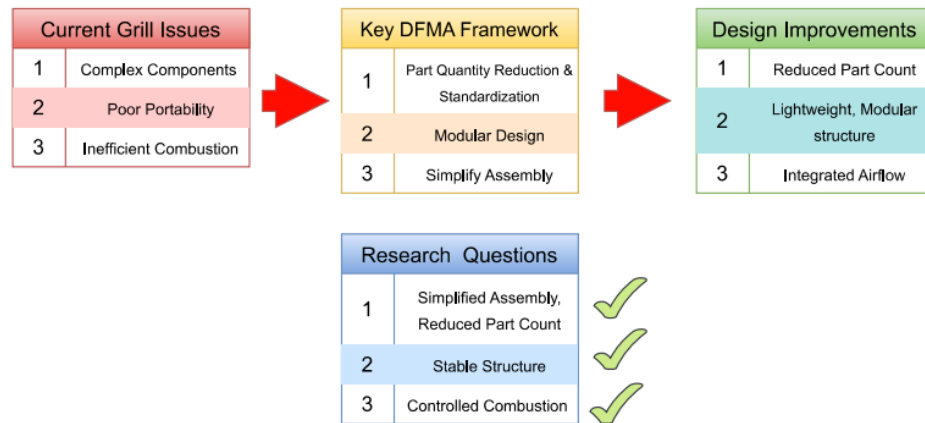


Figure 18 Demonstration of DFMA Framework Relation to the Research Questions

A balanced design which improves usability and manufacturability while maintaining system requirements is enabled through the DFMA approach. The effectiveness of the design approach is confirmed through structural analysis and a thorough evaluation of manufacturability.

5 Conclusion

This thesis outlines the development of a modular charcoal grill intended for efficient use in the Northern European market. The developed system design prioritizes directly addressing usability issues prevalent in currently available market charcoal grills that discourage consumer use due to portability, stability in adverse environments, and thermal inefficiency. The design process adopted DFMA theory and a modular approach to address the consumer practicality needs as well as managing the manufacturability of the product to prioritize efficiency and sustainability. The architecture development was carefully justified in each step, with key considerations to component minimization, combustion efficiency, and material choices. The assembly was modelled using CAD software and analyzed through FEA computation to ensure reliability. The final design was evaluated in respect to DFMA compliance and user serviceability. The study is limited to a conceptual approach with validation supported by CAD modelling and static structural analysis.

System components were carefully evaluated throughout the design process, with an aim to uphold the desired system characteristics while minimizing component complexity and quantity. This strategy allowed for the development of an integrated airflow path, eliminating complex airflow regulation components. Further design simplifications include fully standardized fastening components and eliminating redundant features. The developed system architecture demonstrates a simplified assembly with a minimized quantity of components. The simplified design enables key usability and manufacturability features through the separation of functional elements. The simplified system design allows for efficient airflow, thermal functionality, and portability capabilities which support consumer usability and manufacturability.

Structural analysis validated the structural performance of the simplified grill structure under expected operating conditions. The FEA static structural simulation environment was used to assess stress concentrations within the system with gravity acting on the system components, as well as a distributed force representing food or cooking tools. The stress levels remained within the accepted limits for stainless steel 1.4301, validating the structural integrity of the reduced system.

The DFMA framework guided key decisions in achieving a system architecture design that aligns with the research objectives of modularity, portability, and manufacturability without compromising structural reliability or functionality. Furthermore, the DFMA approach resulted in a materialized resolution of the research questions by meeting current grill issues through the development design modifications which resolve the outlined complexities.

The development of the grill is limited to a theoretical design concept which is modelled in a CAD environment with analysis in a simulated FEA environment to replicate realistic operation conditions. No physical testing or prototyping of the grill design was pursued. Further research in the development of a modular charcoal grill would benefit from a physical prototype build, enhanced thermal and airflow optimization and analysis, varied experimental testing of loadings, and enhanced environmental simulation to account for wind, snow, rain or further complexities. The study contributes to the development of sustainable design and efficient grilling practice.

References

Antony Jose, S. *et al.* (2025) ‘Wear- and corrosion-resistant coatings for extreme environments: Advances, challenges, and future perspectives’, *Coatings*, 15(8), p. 878. doi:10.3390/coatings15080878.

AZoM (2014) *ASTM A36 mild/low carbon steel*. Available at: <https://www.azom.com/article.aspx?ArticleID=6117> (Accessed: 26 April 2026).

Bakeer, T. (2022) *The theory of homogeneity of nonlinear structural systems - A general basis for structural safety assessment*, pp. 1–35.

British Standards Institution (2008) BS EN ISO 14159:2008 Safety of machinery — Hygiene requirements for the design of machinery. London: British Standards Institution. Available at: https://webstore.ansi.org/preview-pages/BSI/preview_30466486.pdf (Accessed: 26 April 2026).

Burgess, D. (2023) ‘NIST Temperature Scale Database.’

CEN (2024) *EN 1860-1:2024 Appliances, solid fuels and firelighters for barbecuing - Part 1: Barbecues burning solid fuels - Requirements and test methods*. European Committee for Standardization.

Chen, W.-L. *et al.* (2022) ‘Heat flow and thermal stress analysis to enhance the temperature distribution and service life of stone grill plates in barbecue ovens’, *Inventions*, 7(4), p. 103. doi:10.3390/inventions7040103.

Chen, J. *et al.* (no date) ‘New insights into the ignition characteristics of liquid fuels on hot surfaces based on TG-FTIR.’ Available at: https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=935284.

Deng, R. *et al.* (2022) ‘Numerical modeling of fixed-bed combustion processes through the multiple thermally thick particle model’, *ACS Omega*, 7(44), pp. 39938–39949. doi:10.1021/acsomega.2c04330.

Global Alliance for Clean Cookstoves (2017) Handbook for biomass cookstove research, design, and development: A practical guide to implementing recent advances. Available at: <https://cleancooking.org/binary-data/RESOURCE/file/000/000/517-1.pdf> (Accessed: 26 April 2026).

Gobell, P., McGill, C. and Willson, T. (2013) *Barbeque Grill Temperature Distribution Design Improvement* [Preprint].

Goldense, B.L. (2022) ‘A history of design for manufacturing and assembly’, *Machine Design*, 94(2), pp. 12–16.

Gumino, B. *et al.* (2020) ‘Design features and performance evaluation of natural draft, continuous operation gasifier cookstove’, *Clean Technologies*, 2(3), pp. 252–269. doi:10.3390/cleantechnol2030017.

Habib, K.A. *et al.* (2011) ‘Breakdown and evolution of the protective oxide scales of Aisi 304 and Aisi 316 stainless steels under high-temperature oxidation’, *International Journal of Corrosion*, pp. 1687–9325. doi:10.1155/2011/824676.

Hayyat, U. *et al.* (2024) ‘CFD simulation of a forced draft biomass cookstove for different airflow conditions’, *Results in Engineering*, 21. doi:10.1016/j.rineng.2024.101928.

Hiiligrilli Pavlof Metalli musta (no date) *Hiiligrilli PAVLOF Metalli Musta*. Available at: https://www.beliani.fi/hiiligrilli-teras-harmaa-79-x-49-cm-pavlof.html?gad_source=1&gad_campaignid=17280201837&gbraid=0AAAAADc0vUaubxYT8Q82N3smJgmOyvtE8&gclid=CjwKCAjwzLHPBhBTEiwABaLsShL7Vhrzk0mJeVoYBOd3fjbQGYnORowu8JJoqCzgMDhSNr-cXuO3MMBoCjZ4QAvD_BwE (Accessed: 26 April 2026).

Huang, L. (2012) ‘A simplified method for numerical simulation of gas grilling of non-intact beef steaks to eliminate escherichia coli O157:H7’, *Journal of Food Engineering*, 113(3), pp. 380–388. doi:10.1016/j.jfoodeng.2012.07.003.

International Organization for Standardization (2021) *ISO 11228-1:2021 Ergonomics—Manual handling—Part 1: Lifting, lowering and carrying*. Geneva: International Organization for Standardization. Available at: <https://www.iso.org/obp/ui/en/#iso:std:76820:en> (Accessed: 26 April 2026).

Jelonek, Z. *et al.* (2021) ‘Emissions during grilling with wood pellets and chips’, *Atmospheric Environment: X*, 12. doi:10.1016/j.aeaoa.2021.100140.

Johnson, E. (2023) ‘Carbon-intensity and carbon-efficiency of charcoal production, by pathway’, *Atlantic Consulting*, 1, pp. 3–17.

Lask, K. and Gadgil, A. (2017) ‘Performance and emissions characteristics of a lighting cone for charcoal stoves’, *Energy for Sustainable Development*, 36, pp. 64–67. doi:10.1016/j.esd.2016.03.001.

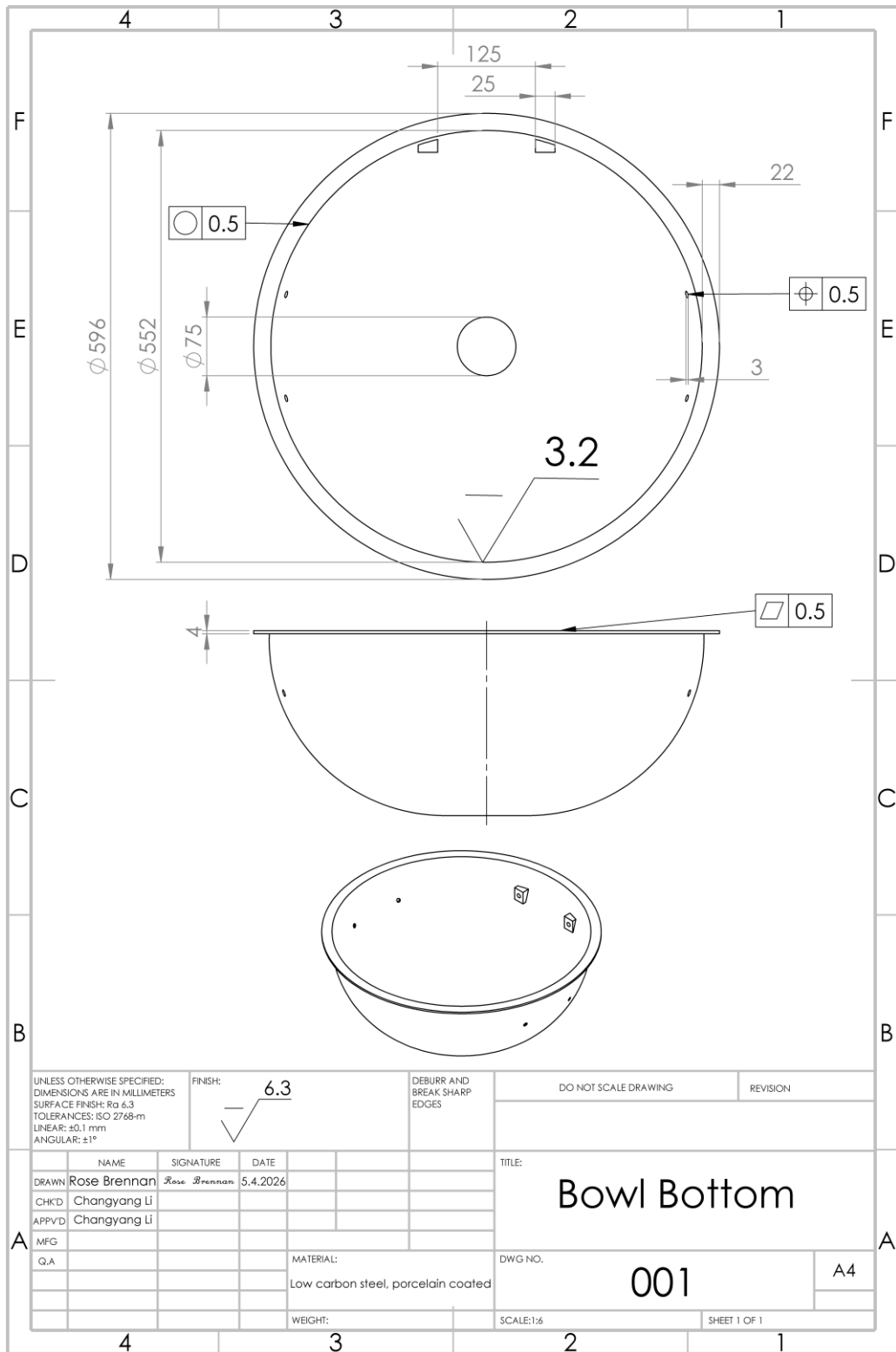
Leer, J. (2016) *Full article: The rise and fall of the new Nordic cuisine*, *Taylor & Francis Online*. Available at: <https://www.tandfonline.com/doi/full/10.3402/jac.v8.33494> (Accessed: 26 April 2026).

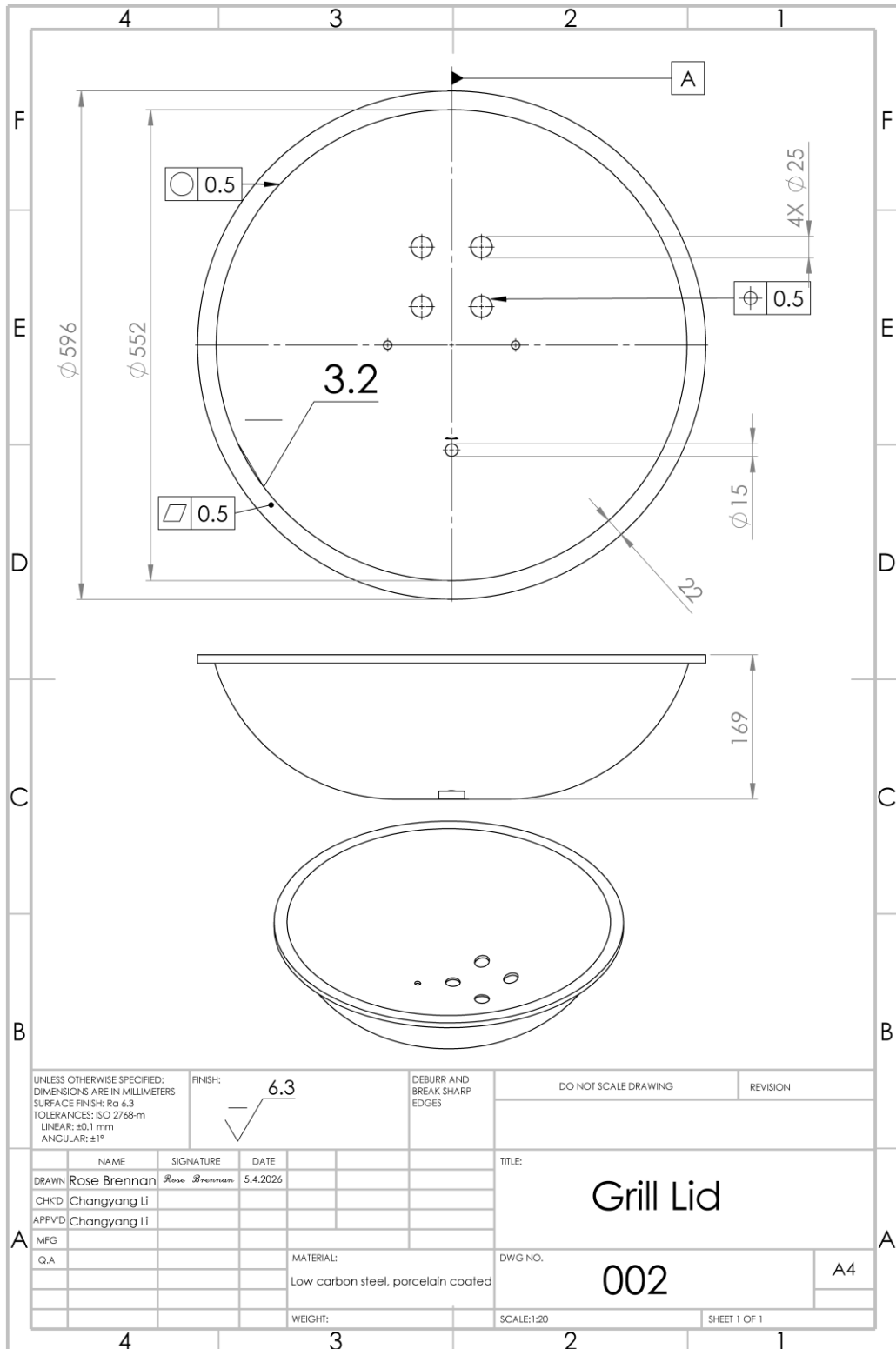
Leer, J. (2022) ‘Gender and Barbecue’, *Anthropology of food*, 16, pp. 1–17. doi:10.4000/aof.12915.

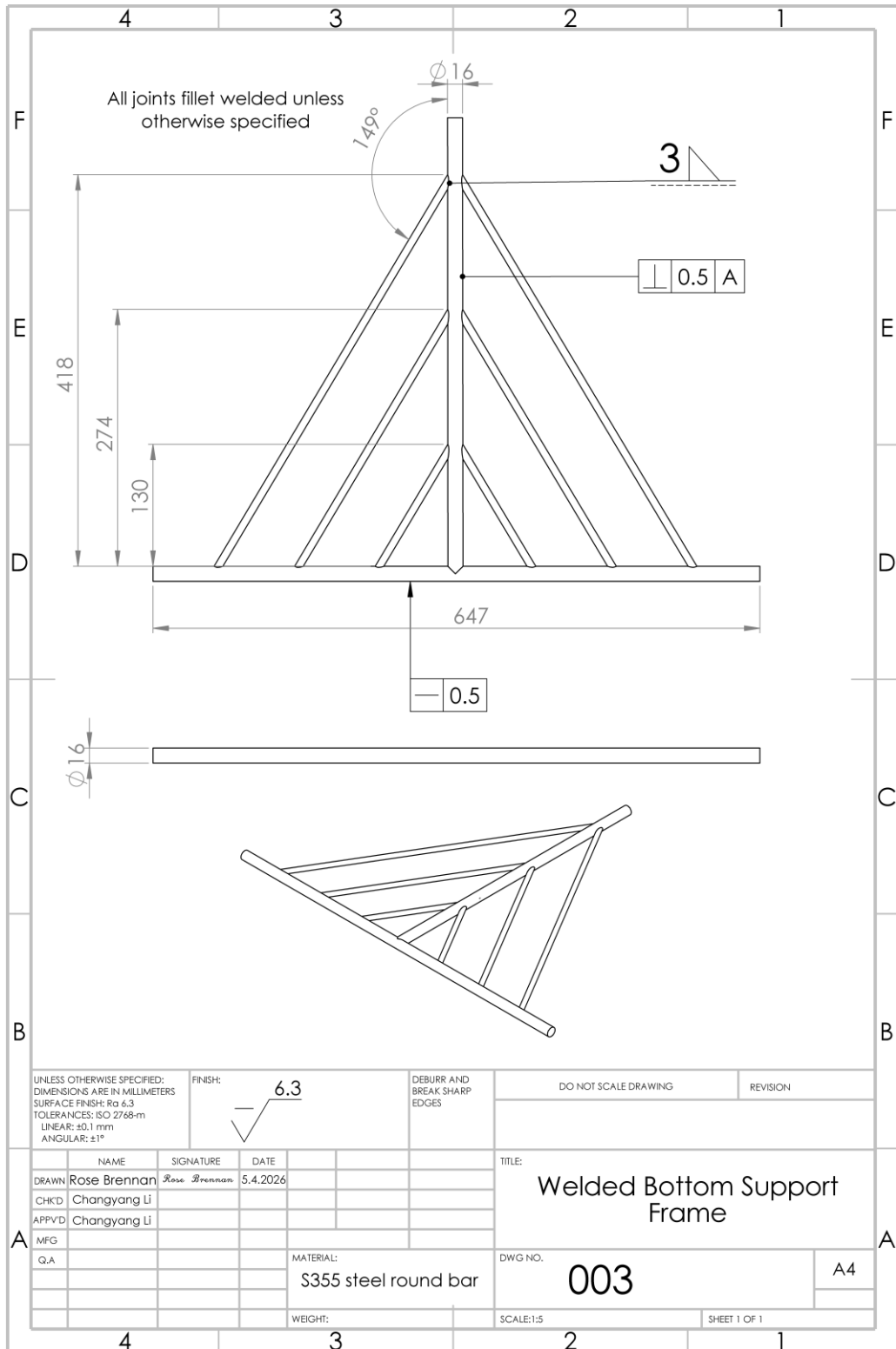
Mencarelli, A. *et al.* (2023) ‘Charcoal-based products combustion: Emission Profiles, health exposure, and Mitigation Strategies’, *Environmental Advances*, 13. doi:10.1016/j.envadv.2023.100420.

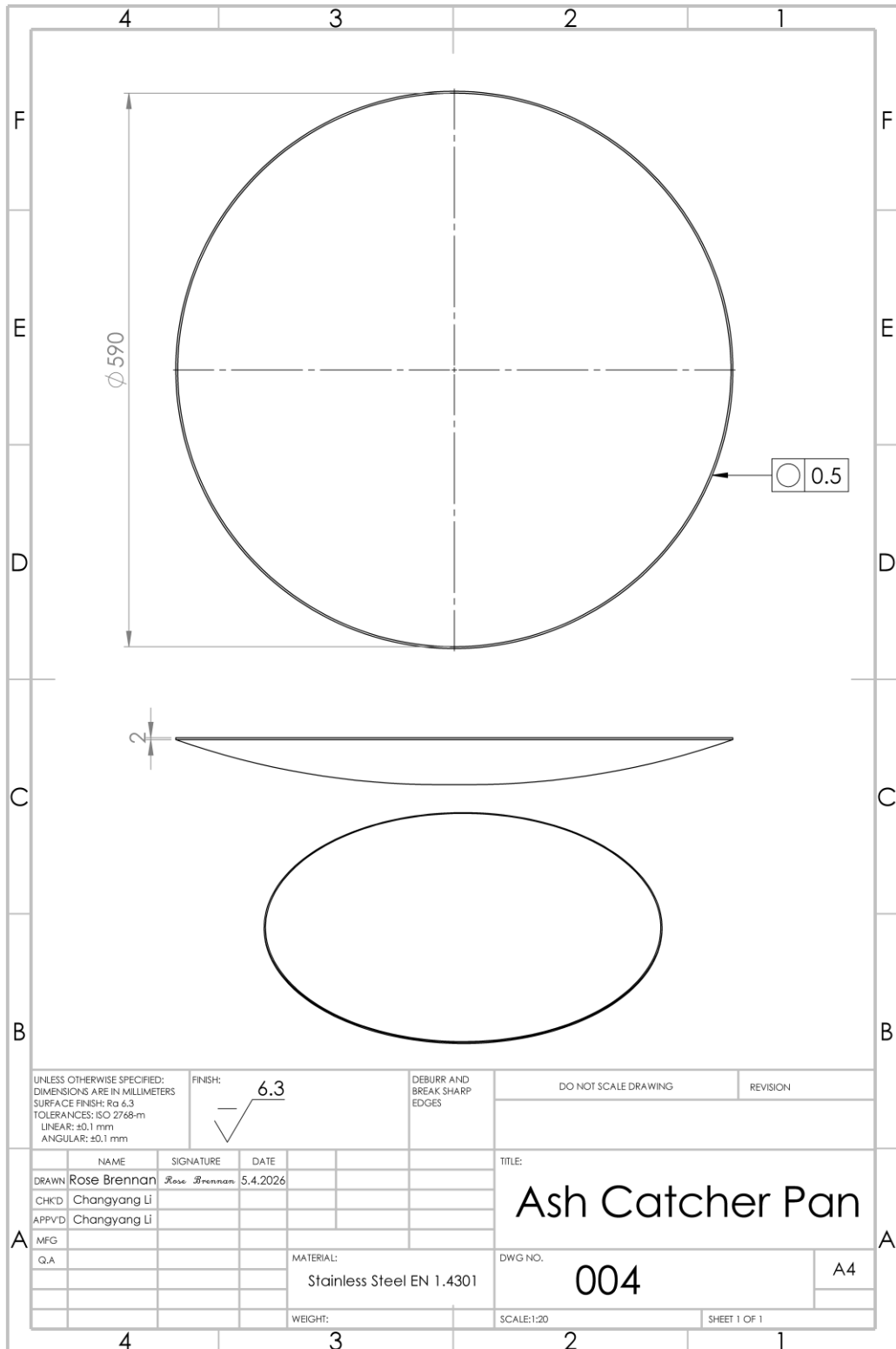
- Perret, M. (2025) *170,000 packs a week: Pilgrim's Europe fires up Summer meat production*, *FoodManufacture.co.uk*. Available at: <https://www.foodmanufacture.co.uk/Article/2025/06/30/pilgrims-europe-is-ramping-up-meat-production-to-cater-for-the-increasing-demand-for-bbqs/> (Accessed: 26 April 2026).
- Rahman, K.A., Leman, A.M. and T, J. (2023) 'The Production of Briquette Charcoal from Coconut Shell and Palm Shell as A Renewable Energy Source', *International Journal of Technical Vocational and Engineering Technology*, 4(1), pp. 1–12.
- Raman, P., Ram, N.K. and Gupta, R. (2014) 'Development, design and performance analysis of a forced draft Clean Combustion Cookstove powered by a thermo electric generator with multi-utility options', *Energy*, 69, pp. 813–825. doi:10.1016/j.energy.2014.03.077.
- Russo, F., Rossi, S. and Compagnoni, A.M. (2021) 'Porcelain enamel coatings', *Encyclopedia*, 1(2), pp. 388–400. doi:10.3390/encyclopedia1020032.
- Sahoo, A. *et al.* (2025) 'Experimental investigation and theoretical analysis of inclined tubes with and without internal rings for natural convection in an energy efficient stove', *Discover Mechanical Engineering*, 4.
- Su, N.K., Iberahim, S. and Choong, C.G. (2025) 'Design and fabrication of Portable Barbecue Grill', *Full Text Proceedings Book [Preprint]*. doi:10.71284/asc.2025139.
- Missouri University of Science and Technology (no date) Temperature measurement. Available at: <https://web.mst.edu/cottrell/me240/resources/Temperature/Temperature.pdf> (Accessed: 26 April 2026).
- Ulrich, K.T., Eppinger, S.D. and Yang, M.C. (2026) *Product design and development*. New York, NY: McGraw Hill.
- Vivek, S. and Kiran, S. (2026) 'Design Aid for Unstiffened Triangular Steel Brackets based on Elastic Stability', *SSRG International Journal of Civil Engineering*, 3(12), pp. 1–16.
- Wei, L. *et al.* (2024) 'Understanding the high-temperature oxidation resistance of heat-resistant austenitic stainless steel with gradient nanostructure', *Corrosion Science*, 231. doi:10.2139/ssrn.4618441.
- Zaffora, A., Di Franco, F. and Santamaria, M. (2021) 'Corrosion of stainless steel in food and pharmaceutical industry', *Current Opinion in Electrochemistry*, 29. doi:10.1016/j.coelec.2021.100760.

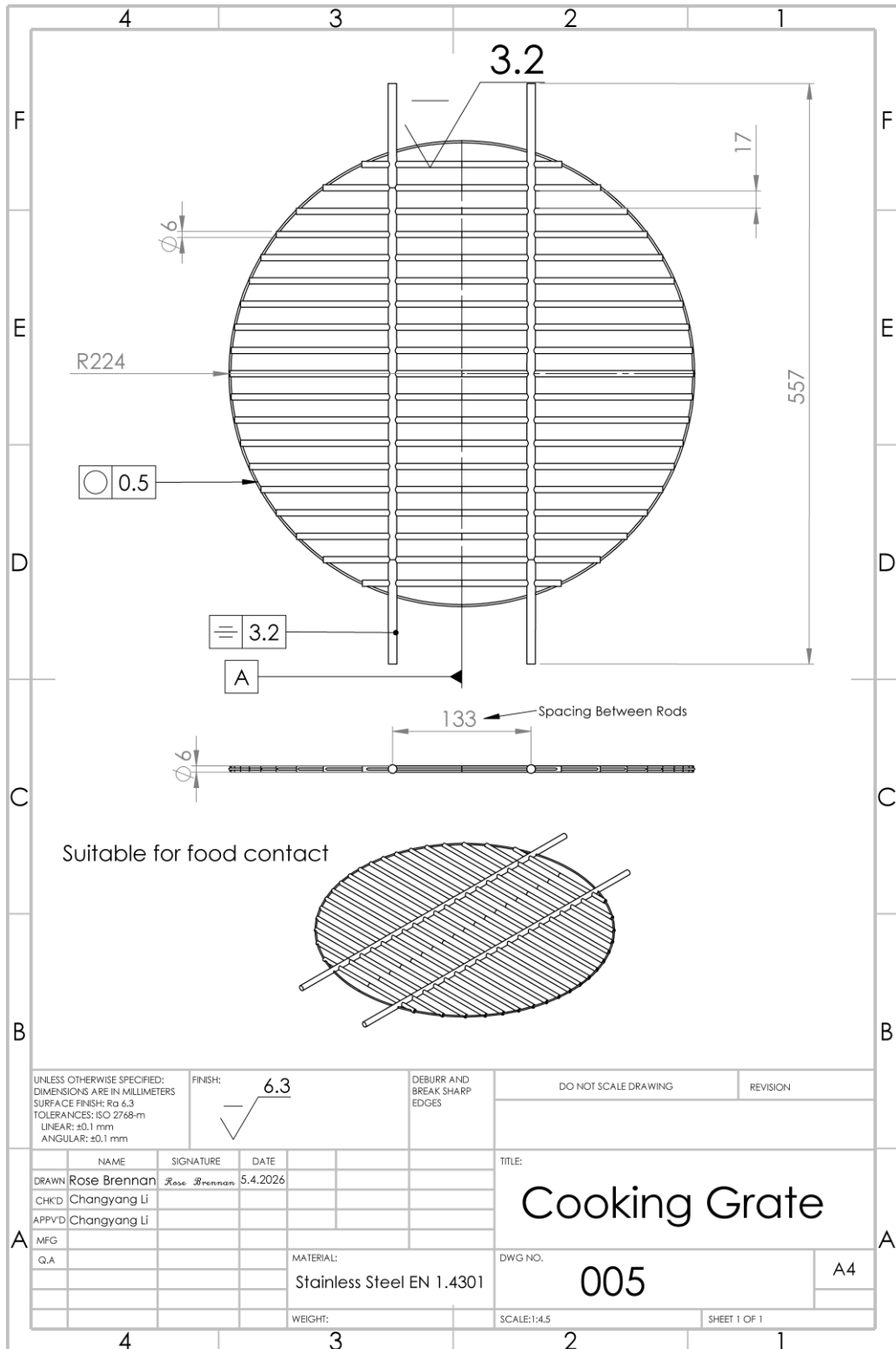
Appendix 1. CAD Drawings

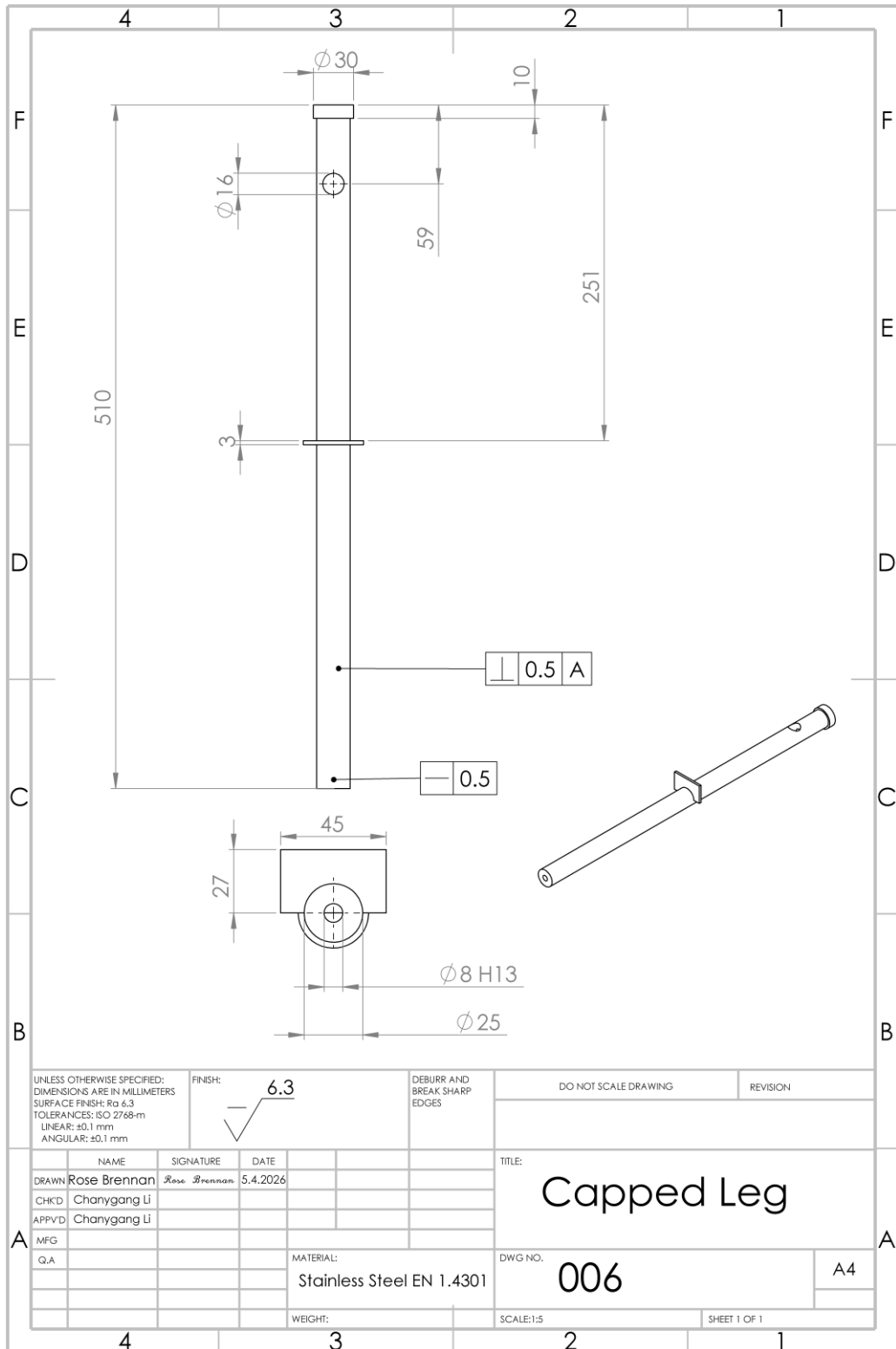


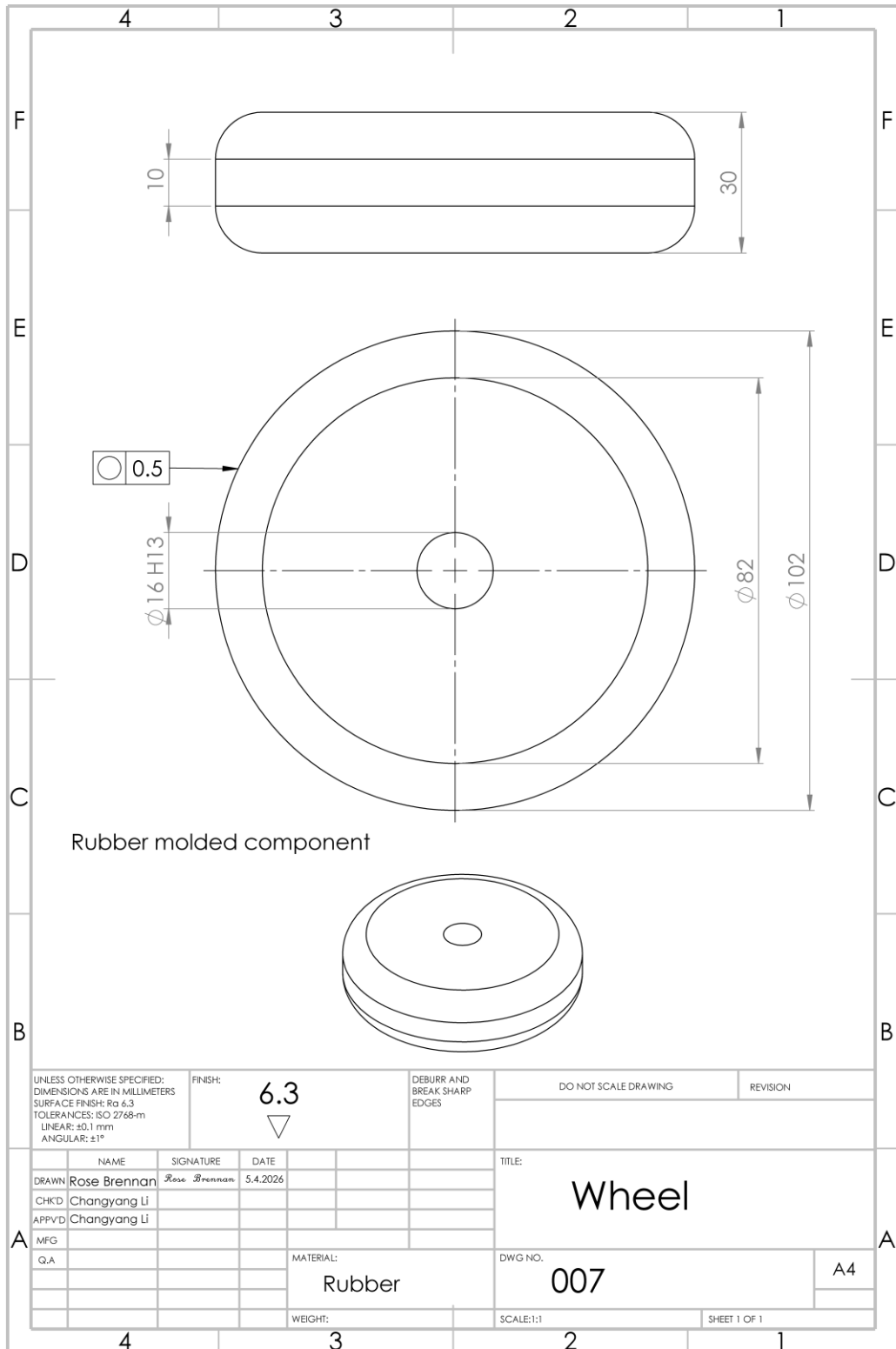


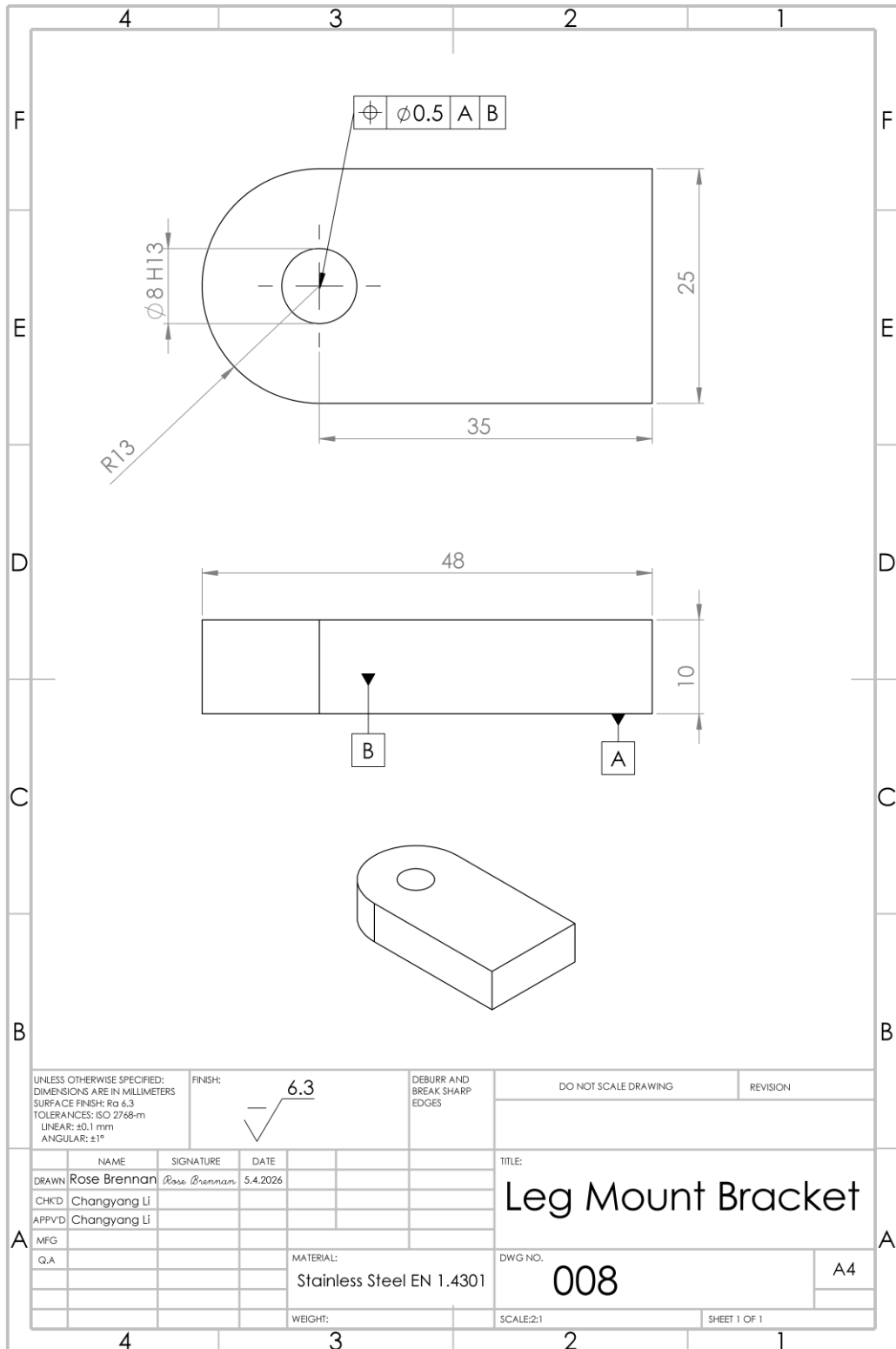












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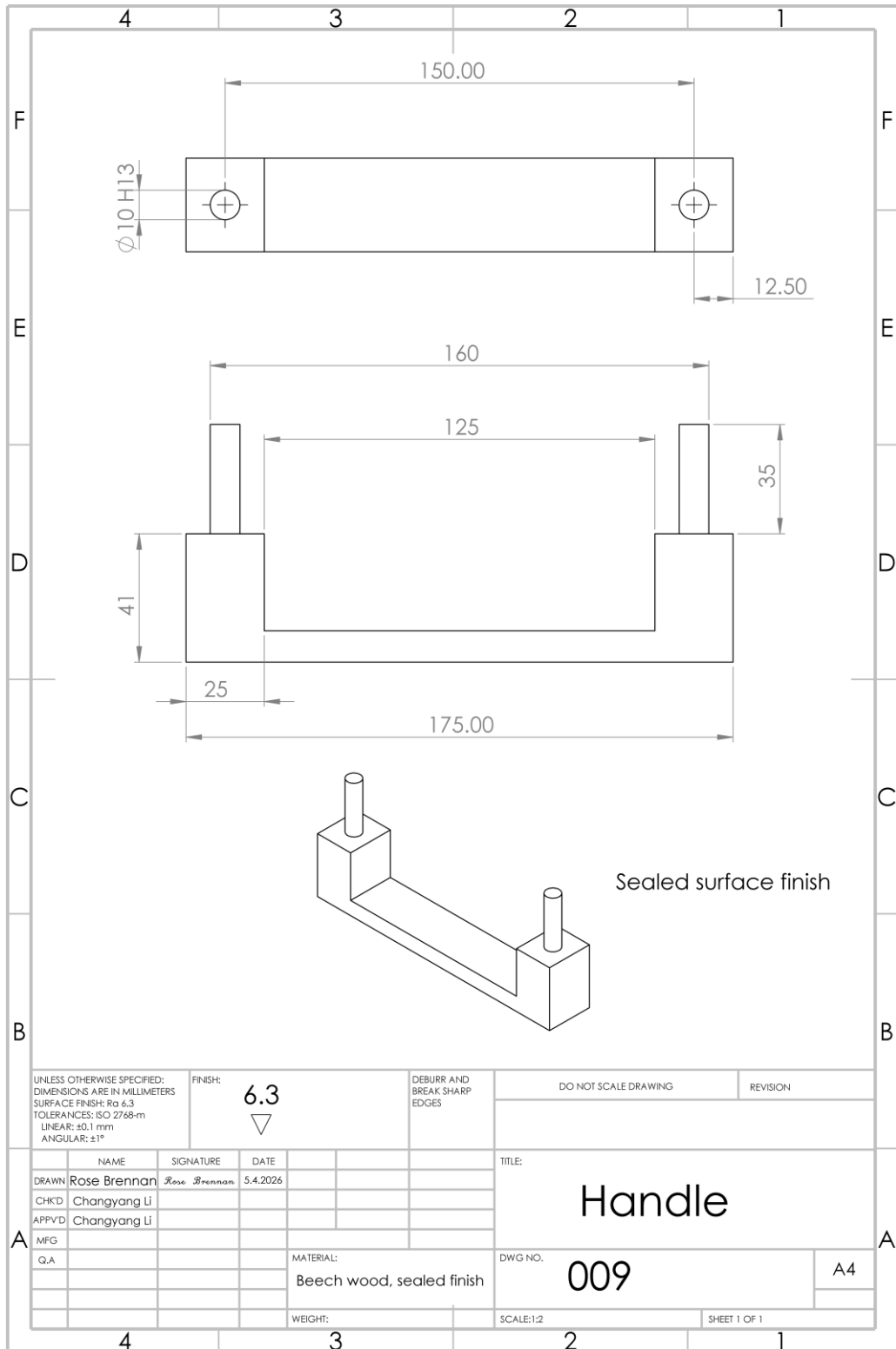
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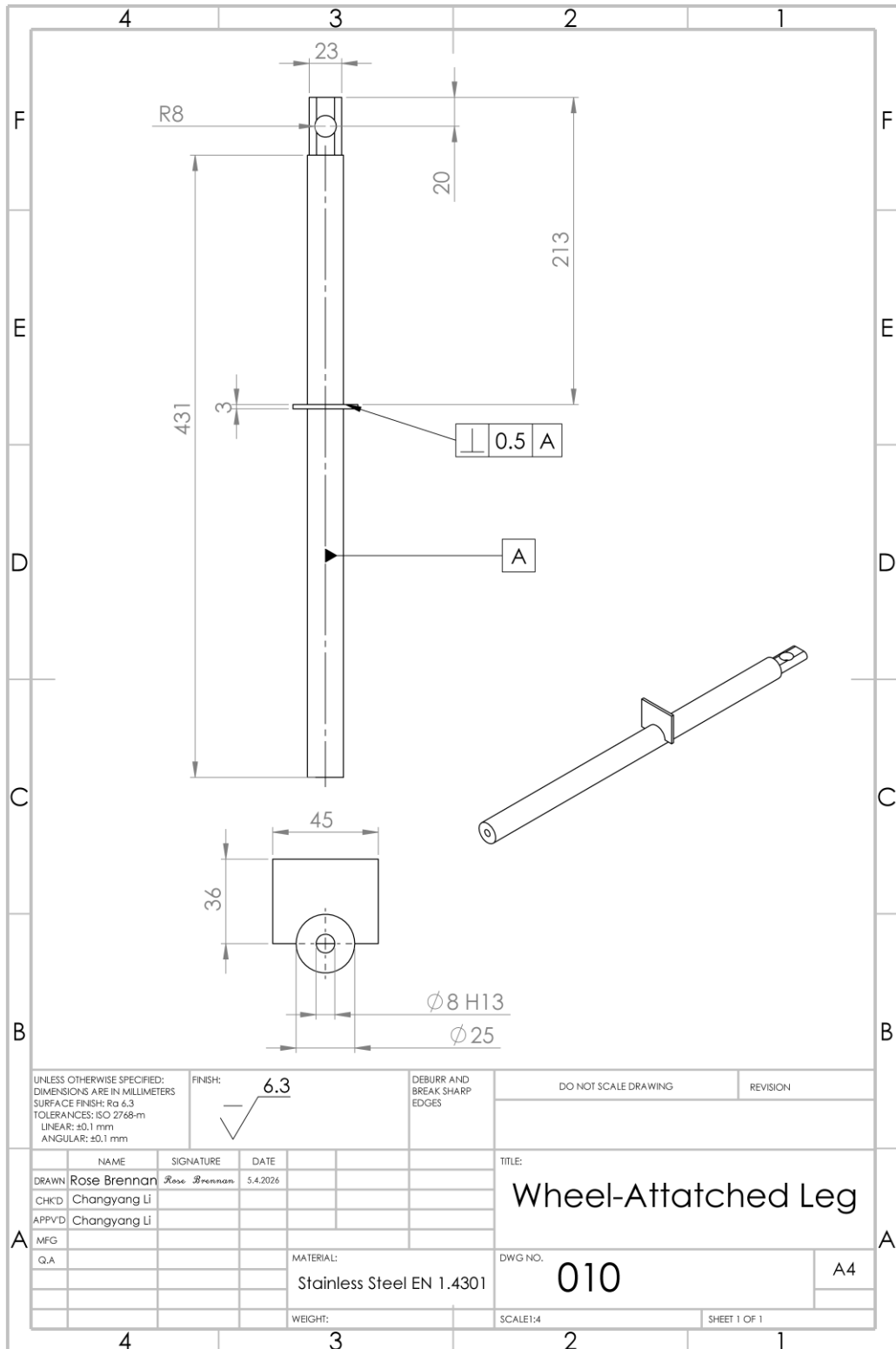
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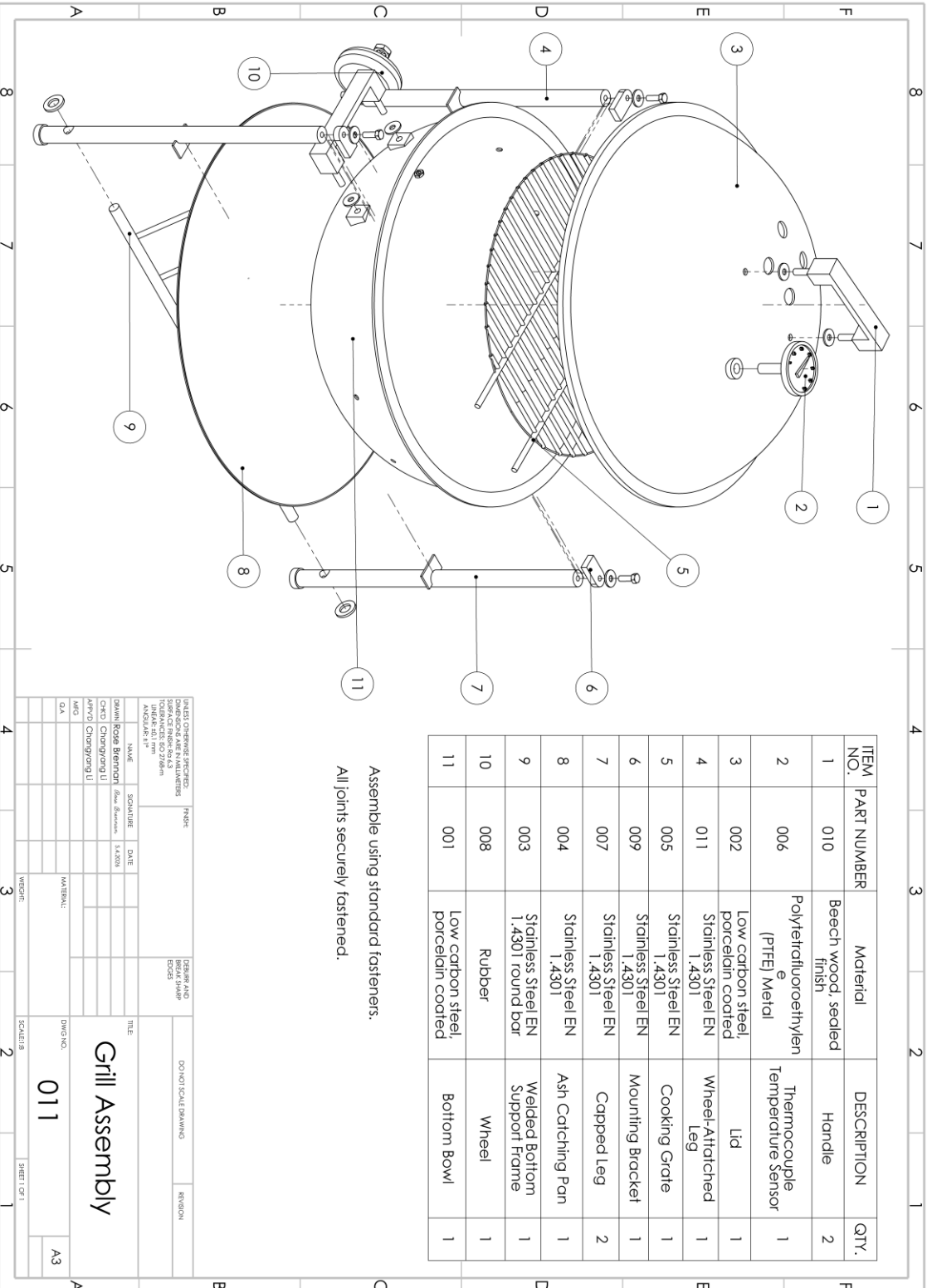
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 Stainless Steel EN 1.4301

WEIGHT:

TITLE: Leg Mount Bracket
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SHEET 1 OF 1







ITEM NO.	PART NUMBER	Material	DESCRIPTION	QTY.
1	010	Beech wood, sealed finish	Handle	2
2	006	Polytetrafluoroethylene (PTFE) Metal	Thermocouple Temperature Sensor	1
3	002	Low carbon steel, porcelain coated	Lid	1
4	011	Stainless Steel EN 1.4301	Wheel-Attached Leg	1
5	005	Stainless Steel EN 1.4301	Cooking Grate	1
6	009	Stainless Steel EN 1.4301	Mounting Bracket	1
7	007	Stainless Steel EN 1.4301	Capped Leg	2
8	004	Stainless Steel EN 1.4301	Ash Catching Pan	1
9	003	Stainless Steel EN 1.4301 round bar	Welded Bottom Support Frame	1
10	008	Rubber	Wheel	1
11	001	Low carbon steel, porcelain coated	Bottom Bowl	1

Assemble using standard fasteners.
All joints securely fastened.

<small>PLEASE CHECK THESE SPECIFICATIONS CAREFULLY BEFORE ORDERING. DIMENSIONS ARE IN MILLIMETERS UNLESS NOTED OTHERWISE. UNLESS NOTED OTHERWISE, DIMENSIONS ARE IN MILLIMETERS.</small>		<small>PLEASE CHECK THESE SPECIFICATIONS CAREFULLY BEFORE ORDERING. DIMENSIONS ARE IN MILLIMETERS UNLESS NOTED OTHERWISE. UNLESS NOTED OTHERWISE, DIMENSIONS ARE IN MILLIMETERS.</small>	
<small>DRAWN</small> Roge Bernhart <small>CHECKED</small> Chongyong LI <small>APPROVED</small> Chongyong LI <small>MFG</small> G.A. <small>QA</small>	<small>NAME</small> Roge Bernhart <small>SCALE</small> Scale: 1:1 <small>DATE</small> 15.02.2023 <small>MATERIAL</small>	<small>TITLE</small> Grill Assembly <small>DWG NO.</small> 011 <small>A3</small>	<small>DO NOT SCALE DRAWING</small> <small>REVISION</small>
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