DESIGN AND FEA SIMULATION OF SELF-CLEANING PUBLIC BENCH

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Abstract. Hygiene issues of public benches frequently congregate in public transport terminals and recreational parks, and reduce user satisfaction, and deteriorate public health. This paper proposes the design of a self-cleaning bench with emphasis to aesthetics, functionality and sustainability. The CAD software SolidWorks was used to design the bench. The primary features of this bench are an automatic rotary brush cleaning system and a manually rotating slat mechanism to provide a new seat surface for each use. Golden ratio has been applied in the design, a well-known mathematical proportion used to create visually appealing figures with both nice looks and strong construction. A material study was done in choosing components that maximise structural durability and efficiency. Finite Element Analysis (FEA) was used to subject the bench to stress, safety, and weight in real conditions. Early FEA outcomes show that the bench structure is within the safe limits of stress during normal usage and changing weather conditions. Later research helped refine the design to achieve measures that will contribute to weight and maintenance optimisation. By forming the combination between conventional design principles and contemporary engineering, this bench brings an ergonomic, visually refined, and hygienic seating choice for the crowded urban environment.

Keywords: public bench design, SolidWorks simulation, motion analysis, strength analysis.

Introduction

Public benches enhance urban space quality and usability because they offer resting areas together with social spaces. Hygiene problems in public benches continue to gather increasing notice from both local authorities and public society. Bench seating poses health risks due to the presence of dangerous bacteria and pollutants which lead to reduced satisfaction among users according to scientific evidence. Scientific analyses show that many communal seating areas demonstrate bacterial contamination so better sanitation measures are needed to fight microbiological threats [1].

As cities grow denser day by day, publicly used resting areas have become used more often. Hence, the demand for better sanitisation on public furniture has risen correspondingly. A recent study has demonstrated that microbes spread through public seating areas because bacteria often show antimicrobial resistance which makes public health management more difficult [2]. Sanitation practices in the urban environment remain inadequate as the bacteria persevere on touched surfaces according to another recent study which suggests immediate regular cleaning protocols and hygiene measures are needed [3]. Furthermore, research focused on urban microbial presence confirms the necessity for regular disinfection of public contact surfaces including benches due to identified health risks [4].

Public seating is considered a key aspect of urban design, which is why it should be easy for people to use without difficulty or health concerns [5]. With the COVID-19 pandemic, people have elevated their concerns for hygiene requirements, especially in public spaces [6]. This has made hassle-free sanitation an important element in urban public seating. This study introduces a novel self-cleaning public bench design that integrates mechanical self-cleaning mechanisms initiated by the user, ensuring a sanitised surface for every use.

Design considerations for public seating

The effectiveness of public seating designs is a combination of numerous principals like better ergonomics, cultural factors and health considerations. In a world where inclusivity and hygiene has taken a driving role of urban development, numerous research efforts have focused on important aspects of how design adaptability is key when hygiene-conscious urban spaces are concerned. When designing public seating an integrated approach for sustainability would be ideal, focusing on durable structures and hassle-free maintenance [7]. Examination of how public seating can reflect cultural identity while improving usability has demonstrated that well-designed benches must balance aesthetic appeal with functional efficiency [8].

Accessibility and inclusivity in public seating

Public seating design must maintain a central priority to serve users from every background such as older adults as well as people who need mobility assistance. The public seating usage and its inclusivity will improve when multiple accessibility features such as armrests, standard seat heights and accessible entrances are included [9]. Social interaction is also improved by well-designed public seating. Hence, universally accessible designs are essential [10].

Innovative seating designs and self-cleaning mechanisms

Novel research continues to direct their efforts toward developing materials that combine innovation with built-in self-elevated cleaning properties for public seating. For example, the application of Kansei Engineering demonstrates that sensory perceptions determine how users accept outdoor seating in scenic locations [11]. Researchers studying seating under windy conditions have identified strategies for increasing durability and cleanliness [12]. This research evidence demonstrates seating systems require both ergonomic and hygienic improvements, therefore modern urban furnishing will benefit from automatic cleaning functions.

This study establishes the design and simulation of a public bench system that cleans itself through user-initiated motion. The design integrates accessible designs and sustainable practices and hygiene concepts to develop urban design research after the pandemic. This self-cleaning bench proposal introduces a novel public seating standard which enhances safety together with comfort for urban settings available to everyone.

Design foundations

Biomimicry was one of the fundamental bases of the design of the bench as was the golden ratio. To ensure that the bench is both structurally integral, ergonomically comfortable and visually harmonious, these principles were applied.

Biomimicry and structural efficiency

The curved side profile of the bench was directly inspired by the contours of an elephant's trunk, as illustrated in Fig. 1.

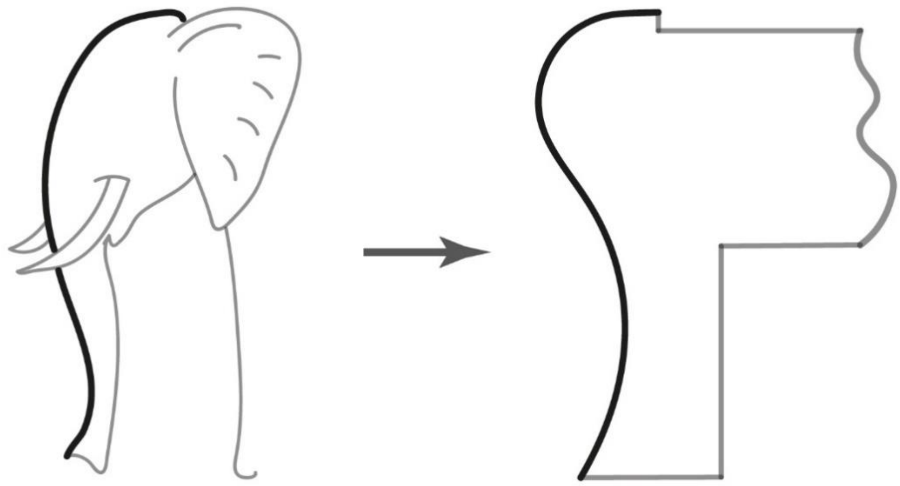

Fig. 1. **Biomimetic bench side profile inspired by an elephant's trunk, optimising strength and ergonomics**

Structural resilience of the bench increases through biomimetic design which distributes applied forces with efficiency for reducing stress concentration zones [13]. The elephant trunk represents remarkable flexibility along with great strength. Its shape has been used to design the curved bench supports which enhance durability through an elegant form. Research in biomimicry shows that biological systems are able to reach maximum distribution efficiency and strength resistance over time [14]. The trunk-like shape of the bench enables the structure to absorb external force impacts without compromising its ergonomic properties needed for comfortable usage. The failure caused by improper stress management (stress concentration) leads to material breakdown in specific areas. However, natural-inspired designs reduce this risk [15].

Golden ratio and proportionality

'Golden ratio' itself is a mathematical construct which is well known for its visual and structural looks, and the park bench design proposed in this scientific study incorporates the same. This was, and is, a ratio which is both aesthetic and functional (approximately 1.618), and it has been widely used in ergonomic and architectural design [16]. Based on the same principle, the curved side of this proposed bench design also conforms to both the visual appeal and structural integrity of the bench. As shown in the sketch dimensions in Fig. 2, the height of the larger curve of 310.01 mm is very precisely manipulated so that the smaller curve of 191.60 mm when multiplied by the golden ratio also has the same height.

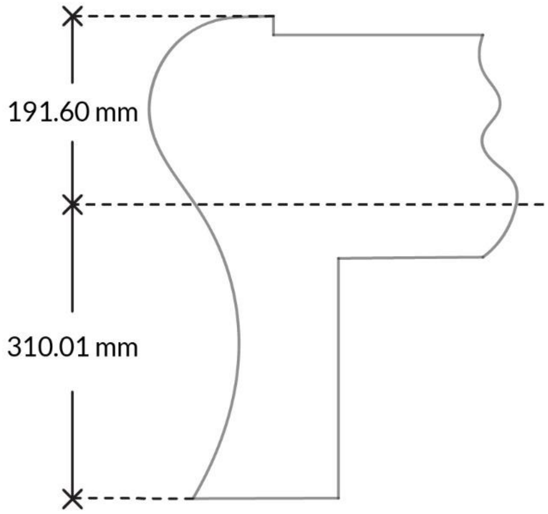

Fig. 2. **Bench profile dimensions applying the golden ratio for structural balance and aesthetics**

The golden ratio is about more than just aesthetics, and it becomes an implementation that creates the presence of natural balance. Throughout history the mathematical principle has appeared in various fields starting from furniture design [17], up to architectural applications [18], and workplace design [19]. The bench utilises a design structure which produces an ergonomically designed and visually sophisticated form by blending functionality with aesthetic beauty. Researchers found that urban settings together with public seating installations follow the golden ratio to enhance user experience [20]. Research on anthropometry demonstrates that golden ratio resembles ergonomic dimensions that optimise comfort and usability standards [21].

Core design and functionality

Fig. 3 presents a durable system that blends functional elements with ergonomic features. The main seating surface includes wooden slats (1) that create a reliable, durable and comfortable space. The wooden slats (1) maintain stability with the slat support (5) which provides structural integrity. Armrests located at both ends of the bench serve to enhance user comfort (2). At either ends of the bench, exist two handles (3) which users can use to manually rotate the slats (1). A special internal belt mechanism (7) enables efficient movement of rotation through one end to the other. Underneath the lower part of the seating unit are four rotary brushes (6) which are contained inside a rotary brush holder.

The refined combination of structural and mechanical components delivers robustness and practical functionality which makes the bench appropriate for public environments with simple operation.

The designed bench functions through a systematic process that ensures the surface is continuously clean and the user effort is minimised. This mechanism makes manual operation compatible with an automated cleaning system for ease of maintenance and achieving hygiene standards. The operational process is depicted in Fig. 4 in a sequential order.

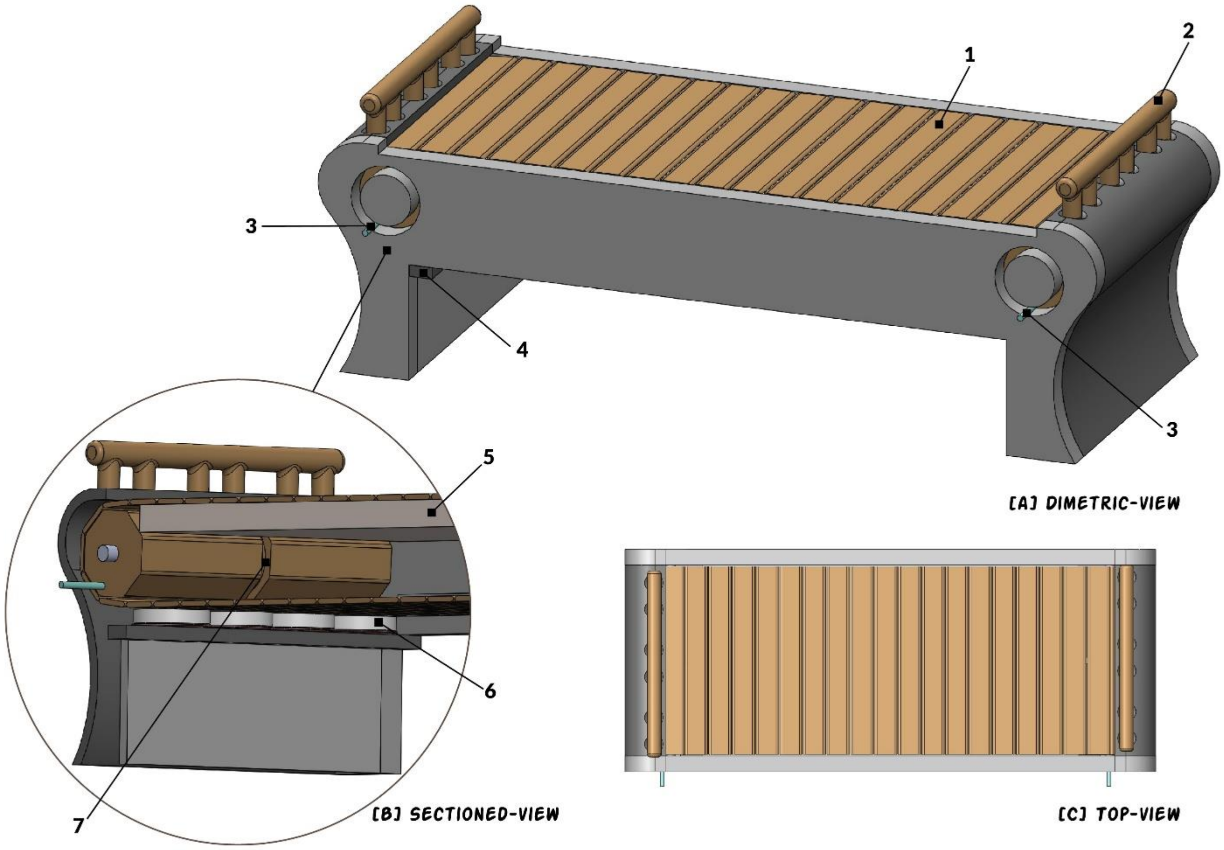

Fig. 3. **Multi-view illustration of the self-cleaning bench design:** (A) Dimetric view showcasing the overall structure, (B) Sectioned view revealing internal components including the cleaning mechanism, and (C) Top view displaying the seating surface configuration

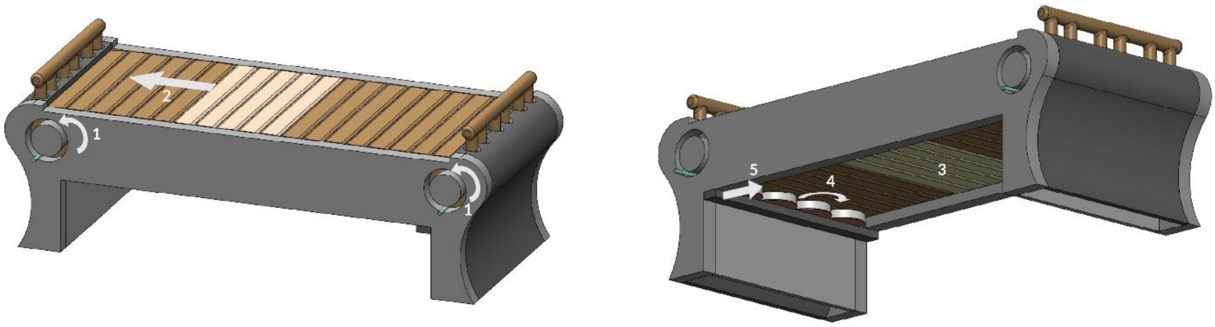

Fig. 4. **Self-cleaning bench operation, showing manual slat rotation (left) and underside cleaning mechanism (right)**

Users initiate the cleaning process through handle rotation (1) that causes wooden slats (2) to move. The movement of handles lets users move uncleaned slats which are shown in Fig. 4 and place them under the seat while revealing a set of clean wooden slats. Underneath, the previously used slats (3) receive automatic cleaning via the rotary brush system (4). An automated brush holder mechanism (5) controls rotational motion of brushes to clean each slat twice (moving from one end to the other and back) before the cleaning cycle completes. Once the cleaning cycle is completed, the slats remain hidden until the next manual rotation.

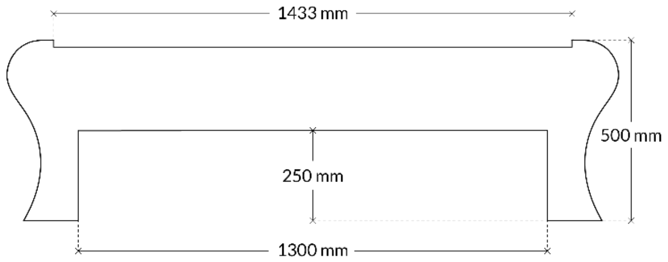

Fig. 5. **Dimensional schematic of the self-cleaning bench**

Brush adaptations

Fixed-holder brush adaptation

As shown in Fig. 6, this adaptation consists of three sets of rotary brushes, the holders of which are static whilst the sets of brushes rotate and clean the seating surface. This design is different from the moving brush holder mechanism of the original iteration. By simplifying, there is less mechanical complexity and complications of maintaining, which still offers effective cleaning. It is particularly suitable for an environment where there may exist moderate cleaning that does not require much motion-based scrubbing.

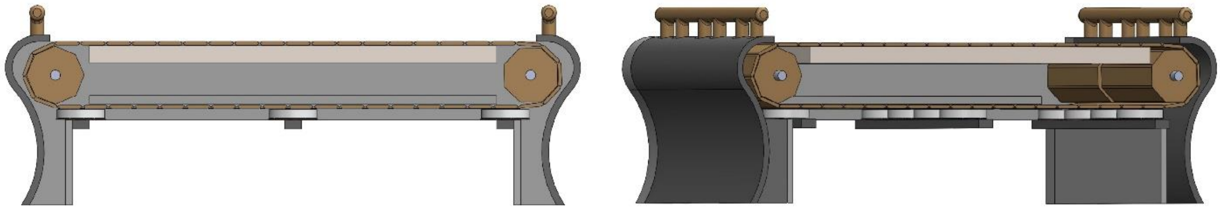

Fig. 6. **Fixed-holder brush adaptation, featuring a simplified cleaning mechanism with three rotary brushes that rotate in place to maintain the seating surface**

Static brush adaptation

In Fig. 7 adaptation of the bench operates without a rotary brush system. The design utilises its brush component as a fixed element that rests under the seating section. When the user rotates the slats, they cause uncleaned slats to touch the brush which uses friction to remove dirt. Such basic structural elements help minimise operational components which leads to less future maintenance requirements. Perforations on the floor of the brush holder work to drop away dislodged dirt directly onto the ground so the mechanism stays free from buildup. The suggested solution would be optimal for public areas that need sustainable and low-attention benches with extended service life.

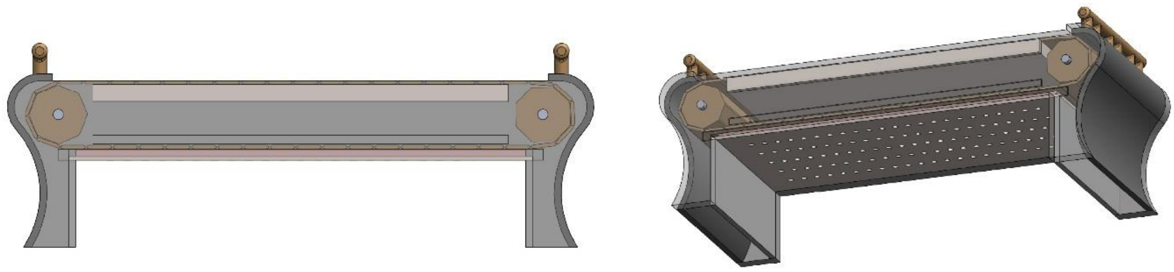

Fig. 7. **Static brush adaptation, featuring a fixed brush beneath the seating surface.** As the slats rotate, friction removes dirt, which falls through perforations to prevent accumulation

Simulations

The structural strength and safety of the bench was assessed via the finite element analysis (FEA) on the bench design. The objectives were to simulate under real load conditions such as the user weight, other loads and gravity to have stress distribution and the factor of safety evaluated. The bench was modelled in SolidWorks and analysed using SolidWorks Simulation. A curvature-based mesh with blended tetrahedral elements was applied. As shown in Fig. 8, the legs were fixed, and gravity was applied downward. Only the static structural analysis was performed to assess the initial design feasibility. Future work could include modal and fatigue analyses to evaluate vibrational and long-term performance.

Boundary conditions

At the two legs, for structural analysis of the bench, the boundary conditions (Fig. 8) involve fixing the bench. A potential load of four individuals all weighing 100 kg each (4,000 N, 4×100×10) and extra load, i.e. baggage or anything else (6,000 N or 6000/10 or 600 kg), are accounted for by the potential seating surface load of 10,000 N. In addition, 9000N of forces are exerted parallel to the wooden slats, which represents variations of seating positions as well as unevenly distributed load. The simulation also included the gravity. In so doing, these conditions ensure a comprehensive evaluation of the bench load bearing capacity and its structural integrity under its realistic usage.

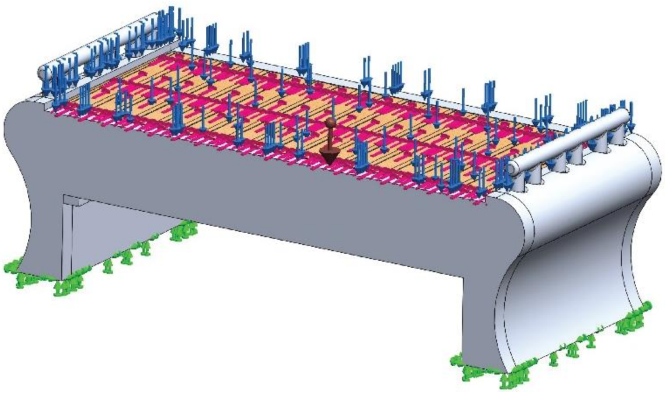

Fig. 8. **Boundary conditions applied to the self-cleaning bench, showing fixed supports, applied forces and gravity considerations**

Materials

Material selection was guided by three key criteria: durability, structural performance, and operational suitability. Aluminium 6061-T6 was used for all load-bearing and structural components due to its high strength-to-weight ratio, corrosion resistance, and excellent machinability, making it ideal for outdoor use. Compared to stainless steel or other aluminium series, it offers a balanced combination of strength, weight, and cost. Balsa wood was chosen for the seating slats because of its low density, which facilitates smooth manual rotation within the cleaning mechanism, while also providing user comfort and thermal insulation. Unlike heavier hardwoods such as teak or pine, balsa offers ease of movement with reduced mechanical load, though at the expense of surface hardness which is acceptable in this rotating context.

Results and discussion

The static structural simulation of the self-cleaning bench under representative loading conditions revealed a maximum von Mises stress of 30.011 MPa, localised at the sprocket support regions (Fig. 9). These areas act as critical load-transfer points, bearing the interaction forces between the rotating slats and the fixed structural frame. The elevated stress concentration here reflects both the mechanical constraint imposed by the cleaning mechanism and the transfer of user loads through the slats into the supports.

In contrast, stress levels across the main frame and seating elements remained relatively low, indicating an efficient global load distribution. The minimum factor of safety (FOS) was 9.2, well within acceptable limits for Aluminium 6061-T6, which has a yield strength of 276 MPa. These results confirm that the design comfortably supports the intended loading without risk of structural failure. Comparable studies on outdoor fixtures, such as urban furniture and equipment frames, similarly report stress localisation at joint or interface zones due to geometry and load application patterns [7, 17]. While the current model demonstrates robust static performance, future work should include fatigue and modal analyses to evaluate long-term durability and vibrational response under repetitive use conditions.

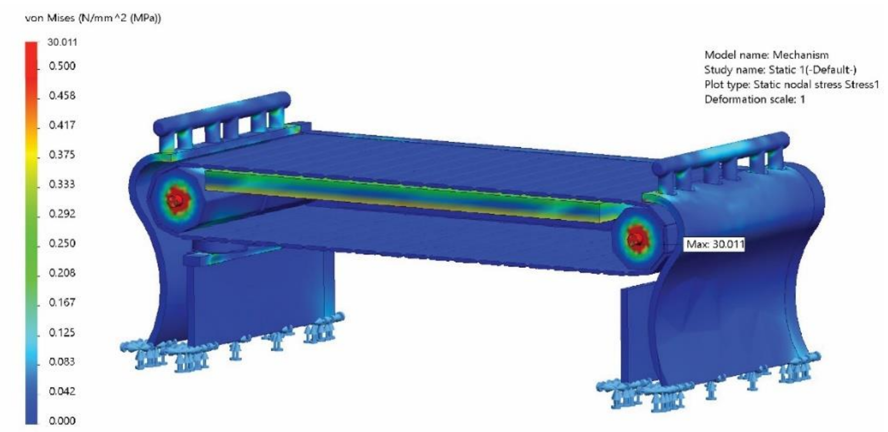

Fig. 9. **Stress simulation results showing the maximum stresses in MPa**

Conclusions

This research presented the conceptualisation, design, and virtual verification of a novel self-cleaning public bench aimed at enhancing hygiene and user comfort in urban environments. The design integrated principles of biomimicry, specifically, structural inspiration from the elephant trunk, and proportional aesthetics based on the golden ratio to achieve both ergonomic and mechanical optimisation. Finite Element Analysis (FEA) was employed to assess the structural response under realistic loading conditions. Results showed a maximum von Mises stress well below the yield strength of Aluminium 6061-T6 and a minimum factor of safety of 9.2, indicating a structurally robust system. Material choices were based on theoretical suitability for outdoor applications: aluminium for its corrosion resistance and strength-to-weight efficiency, and balsa wood for its low mass, rotational ease, and comfort-enhancing properties.

The simulated stress distribution revealed efficient load transfer across the bench structure, particularly around the sprocket support regions, which were identified as the primary load-bearing zones. While these findings validate the design from a computational standpoint, they remain indicative rather than definitive. The absence of physical testing or environmental exposure assessments means that real-world reliability, wear performance, and cleaning mechanism durability remain unverified. Consequently, further studies are essential to support these preliminary findings, particularly full-scale prototyping, cyclic fatigue testing, and environmental simulations under variable conditions. Such future work would provide comprehensive evidence of functional longevity and mechanical stability in operational contexts.

Acknowledgements

The authors express sincere gratitude to Professor Dr.sc.ing. Vladislavs Jevstigņejevs from Riga Technical University Faculty of Civil and Mechanical Engineering for guiding the bench simulation and design work. The valuable insights from Professor Jevstigņejevs led to enhanced structural and operational characteristics of the self-cleaning public bench.

This research was funded by Riga Technical University 2024/2025 Project for Strengthening Scientific Personnel Capacity Nr. ZM-2025/12.

Author contributions

Conceptualisation, K.J.; methodology, K.J. and P.P.; software, K.J. and P.P.; validation, K.J. and P.P.; formal analysis, K.J.; investigation, K.J. and P.P.; data curation, K.J.; writing – original draft preparation, K.J.; writing – review and editing, K.J. and P.P.; visualization, K.J.; project administration, K.J.; funding acquisition, K.J. All authors have read and agreed to the published version of the manuscript.

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