Gutter Cleaning Tool Concept for Mitigating Ergonomics Risk Among Drainage Cleaners in Residential Areas

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ABSTRACT

Manual drainage maintenance in Malaysia is critical for flood prevention but exposes sanitation workers to severe musculoskeletal risks. This study aimed for an ergonomic gutter cleaning tool to mitigate physical strain and enhance efficiency in residential areas. Ergonomic assessments using the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) and Rapid Upper Limb Assessment (RULA) revealed critical biomechanical stress on the hands, wrists, and neck. All participants recorded an overall RULA score of 7, indicating the highest risk level and a need for immediate intervention. Following the Ulrich and Eppinger design framework, five concepts were evaluated. The final selection, Concept 2+, is a hybrid design featuring an adjustable aluminum handle (154–169 cm) with a secure twist-lock mechanism and an optimized ABS scoop. By accommodating varying worker heights and improving scoop geometry, the tool addresses awkward postures such as excessive bending and repetitive wrist deviation. Implementation of this ergonomic solution is expected to reduce the risk of cumulative trauma disorders and improve maintenance productivity.

Keywords: Drain maintenance, Ergonomic design, Gutter cleaning tool, Prototype development, Worker efficiency

1. INTRODUCTION

Effective drainage maintenance plays a critical role in preventing flooding and sustaining public hygiene, particularly in Malaysia's urban and residential areas, where stormwater management is a persistent challenge. Household waste constitutes approximately 81% of total municipal solid waste, and improper disposal often clogs roadside drains, contributing to flash floods [1]. The Department of Irrigation and Drainage (DID) is tasked with maintaining urban and rural drainage systems, yet manual drain cleaning remains the most common practice. Sanitation workers, particularly those employed by concession companies such as Alam Flora Sdn. Bhd. and the Solid Waste and Public Cleansing Management Corporation (SWCorp) play a crucial role in clearing debris from gutters and the roadside drain system, as illustrated in Figure 1. However, this essential task exposes them to physical strain and ergonomic risks [2].

Figure 1. Gutters and the roadside drainage system in the investigation field

1.1 Problem identifications

Existing gutter cleaning tools used in residential maintenance exhibit several deficiencies, including limited scoop size, insufficient reach, and non-ergonomic handle design, as illustrated in Figure 2. These shortcomings reduce cleaning efficiency and compel workers to adopt awkward postures, such as excessive bending, which increases the risk of musculoskeletal disorders (MSDs). The limited stick height also restricts access to deeper drains, causing incomplete debris removal and contributing to frequent re-clogging.

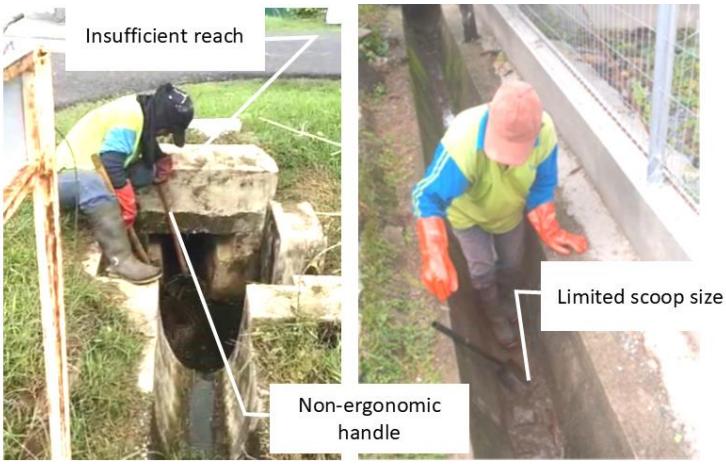

Figure 2. Gutter cleaning tool problems in cleaning activities

1.2 Objectives and Study Scope

This project aims to develop an ergonomic gutter cleaning tool that enhances efficiency, accessibility, and worker comfort. The objectives are: (i) to improve the size and geometry of the drain scoop based on residential drain dimensions, (ii) to design a stick with anthropometric and ergonomic considerations to reduce awkward postures, and (iii) to evaluate the tool's ergonomic performance, efficiency, and accessibility in field applications.

The scope of this research focuses on the design and fabrication of a drain scoop suitable for residential drainage systems with widths ranging from 4 to 6 inches. The tool includes an adjustable stick length, up to 130 cm, to accommodate sanitation workers of varying heights (150–180 cm) while minimizing bending and reaching postures. The outcomes are expected to

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enhance worker well-being, reduce cleaning time, and contribute to improved flood prevention through better maintenance practices.

2. MATERIAL AND METHODS

2.1 Problem Identification

The study began with identifying ergonomic and functional problems faced by sanitation workers during drain cleaning activities in residential park areas. Field data were collected through structured observations, surveys, and interviews with sanitation workers from the E-Idaman Group of Companies, located at Jalan Jati, Taman Sri Wang, Arau, Perlis. A total of five male workers aged between 21 and 49 years participated voluntarily. It is important to acknowledge that this sample size is relatively small, which serves as a limitation of the current study. Consequently, the findings regarding musculoskeletal discomfort and postural risks may not be fully generalizable to the broader population of sanitation workers across different regions or demographics. However, this sample size was deemed sufficient for this preliminary exploratory design study, as the primary goal was to identify consistent, high-risk ergonomic patterns—such as the RULA score of 7 found across all participants—to inform the rapid development of a functional tool prototype. To quantify ergonomic risk factors, three assessment approaches were utilized which Initial Ergonomic Risk Assessment (i-ERA) to identify broad environmental and physical risk factors—such as temperature, repetitive motion, and awkward postures—that impact the workers' musculoskeletal health, Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) to identify discomfort frequency and intensity in the hand area, and the Rapid Upper Limb Assessment (RULA) method to evaluate posture-related risks. The CMDQ was administered after routine cleaning sessions to capture realistic working conditions [3]. Observation sessions were conducted to analyze postures and repetitive movements used during daily operations, with surveys administered after routine sessions to capture realistic working conditions.

2.2 Concept Generation

The design activities followed Ulrich and Eppinger Design framework [4]. Customer needs, derived from survey and interview data, were translated into engineering requirements using the House of Quality (HOQ) matrix [4]. Key design parameters—including scoop geometry, handle length adjustability, grip diameter, and tool weight distribution—were established based on standard anthropometric data produced by the National Institute of Occupational Health, Malaysia. Specifically, the grip diameter was designed to accommodate the 5th to 95th percentile of the Malaysian male population's hand breadth and grip span, ensuring a secure power grip that minimizes direct tissue compression in the metacarpal area. Furthermore, the handle length was calculated to allow workers within the 150–180 cm height range to maintain a trunk flexion angle of less than 20°, significantly reducing the biomechanical load on the lumbar region. Five concept sketches and 3D models were developed using CATIA V5 software to visualize possible design solutions.

The key design parameters considered included scoop geometry, handle length adjustability, grip diameter, and tool weight distribution. Five initial concepts were generated and evaluated through concept screening and concept scoring matrices. Each concept was assessed against criteria such as functionality, manufacturability, ergonomics, cost, and user comfort using Pugh method [4]. The highest-scoring concept featured an adjustable-length handle to suit users of varying heights and an optimized scoop angle to improve debris collection and minimize resistance during use.

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3. RESULTS AND DISCUSSION

Five preliminary design concepts were generated to address the inefficiencies and ergonomic issues of existing gutter cleaning tools. Each idea was evaluated using concept screening and scoring matrices based on ergonomics, usability, manufacturability, cost, and performance criteria.

3.1 Results of Ergonomics Risk Assessments

3.1.1 Results of i-ERA

The i-ERA screening served as the foundational assessment to categorize environmental and physical stressors. Figure 3 illustrates the ergonomic risk factors reported by five gutter and drain cleaners using a scoop tool in a residential setting. The findings indicate that all workers identified temperature, repetitive movements, and awkward postures as significant risk factors, highlighting the influence of environmental conditions and the physical demands of the task on musculoskeletal health. Repetition and awkward posture are particularly associated with the design and use of the scoop, as frequent bending, reaching, and twisting during scooping increase musculoskeletal load. Moderate-risk factors, reported by some workers, include forceful exertion and maintaining static or sustained postures, suggesting that the scoop may require considerable strength or prolonged positioning, which can exacerbate physical strain. Low-risk factors such as ventilation, lighting, and vibration were not reported as concerns in this context. These results underscore the need for ergonomic intervention, especially redesigning the scoop to feature adjustable handles, lightweight materials, and comfortable grips.

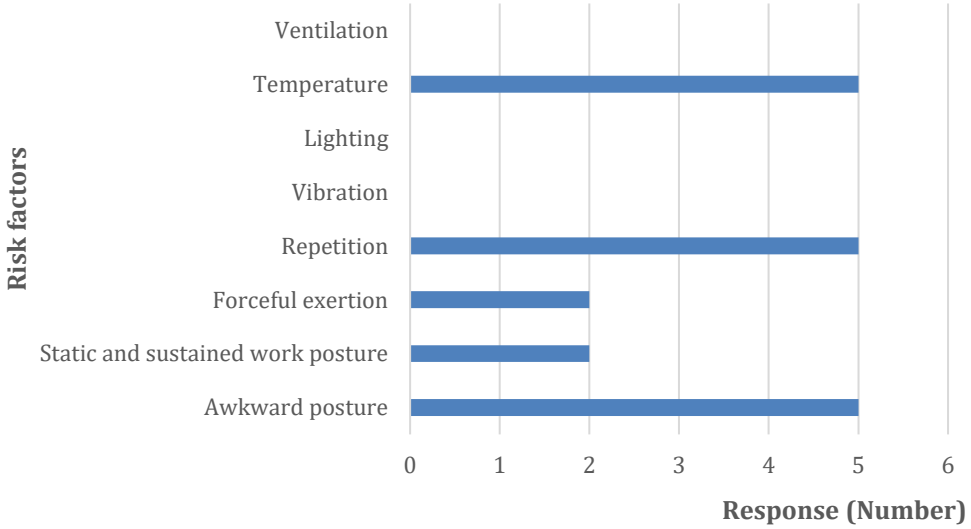

Figure 3. Results of i-ERA

Figure 4 presents the prevalence of musculoskeletal pain reported by five gutter and drain cleaners in a residential area. The data indicate that the most frequently affected body regions are the hands, wrists, shoulders, and neck, each reported by all five workers, suggesting these areas are subjected to the highest biomechanical load during work activities such as scooping, lifting, and reaching. Two workers reported the upper back, while the lower back was reported by one worker, indicating moderate to low prevalence of discomfort in these regions. No reports were noted for the lower limbs, hips, or thighs, suggesting that these areas are minimally impacted by the task demands. The results highlight that repetitive hand movements, sustained awkward postures, and forceful exertion likely contribute to discomfort in the upper extremities and neck. These findings underscore the need for ergonomic interventions relating to hand tools.

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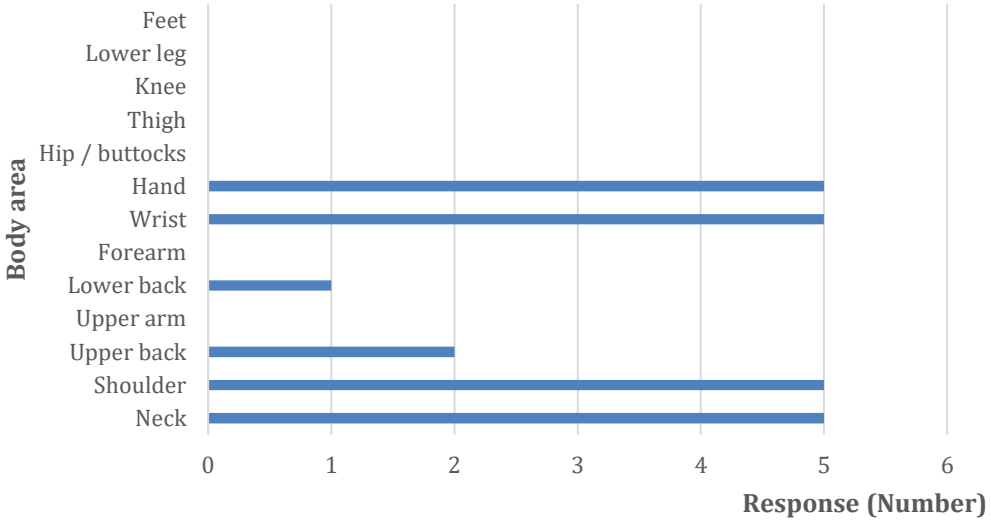

Figure 4. Results of musculoskeletal pain

3.1.2 Results of CMDQ

The CMDQ results indicated that all five cleaners experienced musculoskeletal discomfort in both hands during cleaning tasks. The most critical hand region is the Thenar Eminence, i.e. base of the thumb or adjacent carpal area, and the Metacarpal or Centre of the Palm region, as shown in Figure 5. Discomfort localized to the Thenar Eminence is biomechanically consistent with the forceful gripping and repetitive wrist deviation inherent in operating manual tools, such as augers and drain snakes, which significantly increase the likelihood of developing Cumulative Trauma Disorders (CTDs) like De Quervain's tenosynovitis or carpal metacarpal arthritis. Concurrently, the substantial discomfort reported in the Metacarpal area is directly attributable to the high static muscle load and direct tissue compression sustained by maintaining a high-force power grip on tool handles, a key factor associated with palm-side neuropathies and general grip strain.

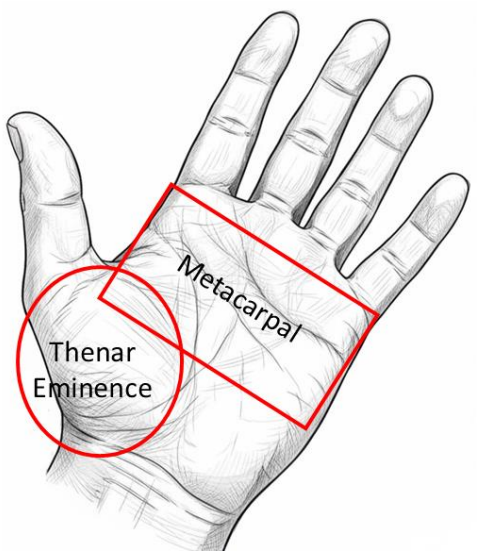

Figure 5. Critical hand regions from CMDQ results (AI generated picture)

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3.1.3 Results of RULA

Table 1 shows the Rapid Upper Limb Assessment (RULA) results for the five gutter and drain cleaners using a scoop tool in a residential area, indicating a consistently high level of ergonomic risk across all participants. Specifically, the scores for the arm and wrist region were uniformly 5, suggesting that these body parts are subjected to significant repetitive or awkward postures, including prolonged flexion, extension, or deviation during scooping tasks. Similarly, the neck, trunk, and leg region scored 6 for all participants, reflecting sustained awkward postures such as forward bending, twisting, and prolonged stooping, which are commonly required when cleaning gutters at ground level or along residential rooftops. The overall RULA scores are consistently 7, which corresponds to the highest action level, indicating that immediate ergonomic intervention is necessary to reduce the risk of musculoskeletal disorders. These findings highlight that the repetitive manual handling and non-neutral postures associated with the scoop tool uses place substantial biomechanical stress on the workers' musculoskeletal system, particularly in the upper limbs and spinal regions, and necessitate urgent modifications to work methods, tools, or postural support to prevent long-term injury.

Table 1. RULA results among five gutter and drain cleaners

	RULA results				
Body area / Participants	**1**	**2**	**3**	**4**	**5**
Arm and wrist	5	5	5	5	5
Neck, trunk and leg	6	6	6	6	6
RULA score	7	7	7	7	7

3.2 Results of Concepts Generation

3.2.1 Concept 1: Fixed-Length Drain Scoop

Figure 6 illustrates Concept 1 features a simple fixed-length handle made of stainless steel with a narrow metal scoop. Although the tool demonstrated adequate structural strength and durability, it lacked adaptability to different user heights and drain depths. The fixed handle length forced workers to adopt awkward postures, resulting in limited ergonomic improvement. Moreover, the scoop's narrow profile reduced the debris collection rate, leading to longer cleaning durations.

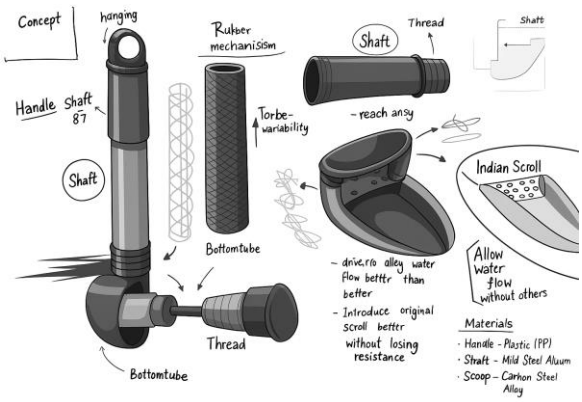

Figure 6. Concept 1 Fixed-length drain scoop

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3.2.2 Concept 2: Adjustable-Length Handle with Clip Lock

Figure 7 illustrates Concept 2 introduces a telescopic handle mechanism secured by a clip lock. This design allowed the handle to be extended or shortened according to user preference. The concept improved accessibility for drains of varying depths and reduced excessive forward bending. However, the clip lock system required high force to engage and occasionally slipped under load, indicating the need for a more stable locking mechanism.

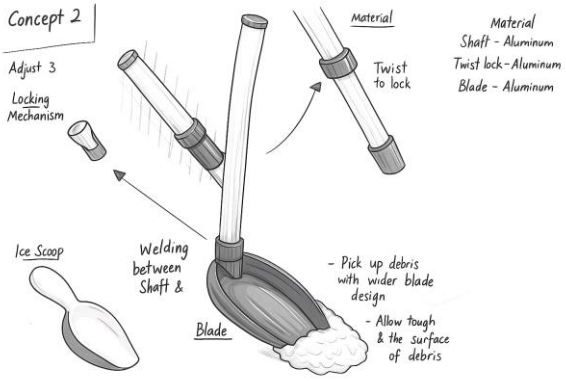

Figure 7. Concept 2 Adjustable-length handle with clip lock

3.2.3 Concept 3: Detachable Scoop with Angled Geometry

Figure 8 presents Concept 3 incorporates a detachable scoop with an optimized 35° working angle to improve debris pickup efficiency. The detachable feature facilitated easier cleaning and replacement of the scoop. Although this configuration enhanced usability and cleaning performance, the additional connection joint increased the tool's overall weight and introduced slight instability at the interface between the scoop and handle.

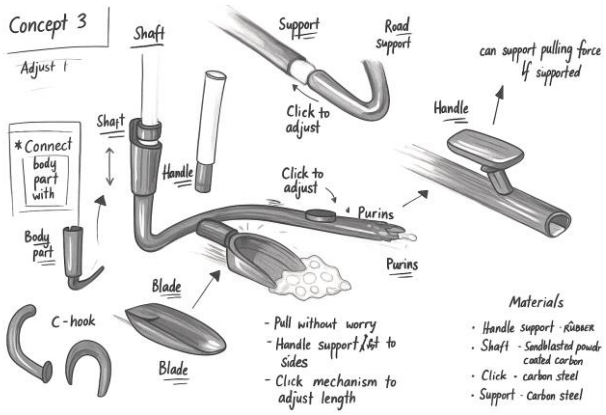

Figure 8. Concept 3 Detachable scoop with angled geometry

3.2.4 Concept 4: Ergonomic Handle with Curved Grip

Figure 9 shows Concept 4 emphasizes ergonomic comfort, featuring a curved handle designed based on anthropometric data to maintain a neutral wrist posture. The rubberized grip surface reduced hand fatigue during repetitive use. However, the overall handle design lacked modularity

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for adjusting length, limiting its adaptability. Additionally, the manufacturing cost was higher due to the use of composite materials.

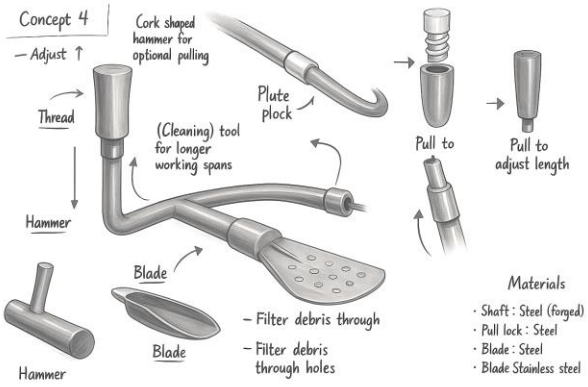

Figure 9. Concept 4 Ergonomic handle with curved grip

3.2.5 Concept 5: Multi-Function Scoop with Drain Filter Attachment

Figure 10 shows Concept 5 integrates a multi-function scoop with small perforations to separate water and debris, improving the cleaning process in wet conditions. Although this feature demonstrated strong cleaning performance in shallow drains, the additional drain filter attachment complicated maintenance and increased fabrication cost.

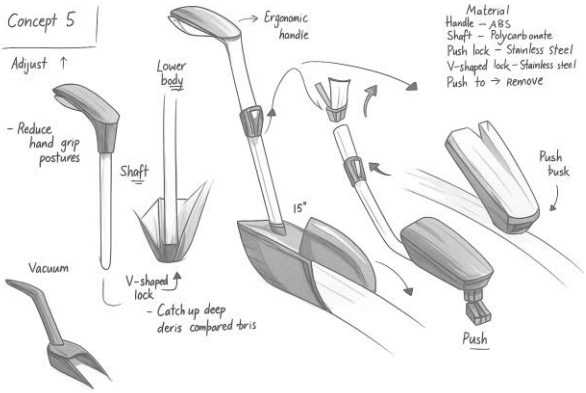

Figure 10. Concept 5 Multi-function scoop with drain filter attachment

3.2.6 Final Concept Selection

Figure 11 shows the final gutter cleaning tool concept based on the concept scoring matrix, Concept 2+, a hybrid design combining the adjustable-length mechanism of Concept 2 with the ergonomic handle of Concept 4, which achieved the highest evaluation score. This concept provides a clear distinction between mechanical design justifications and the ergonomic evidence required to mitigate worker health risks. The design incorporated an adjustable aluminum handle (154–169 cm) with a secure twist-lock mechanism. The handle's maximum extension of 169 cm was determined based on the 95th percentile of male standing knuckle height and functional reach, ensuring that even taller workers can operate the tool without excessive stooping. The grip diameter was set at 35–40 mm, which aligns with ergonomic standards for power grips to maximize torque while reducing the risk of De Quervain's tenosynovitis. Additionally, the 15°–35° angle of the scoop interface was optimized to keep the wrist in a neutral zone during the

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lifting phase of the cleaning cycle, addressing the repetitive wrist deviation identified in the RULA assessment . The use of a lightweight ABS scoop and a non-slip ergonomic grip further minimizes muscle fatigue and improves operational control. To validate the ergonomic benefits of Concept 2+, a simulated RULA assessment was performed by modeling the tool's usage against the baseline data collected in Table 1. While the original tool compelled workers to adopt a RULA Action Level 4 (Score 7) due to excessive trunk flexion and repetitive wrist deviation , the proposed design significantly improves these postures. By utilizing the 154–169 cm adjustable handle, the simulated trunk posture is moved toward a neutral upright position, reducing the trunk score from 6 to 2. Furthermore, the ergonomic curved grip is designed to maintain a neutral wrist orientation, projected to lower the arm and wrist score from 5 to 3. These simulated improvements suggest a total RULA score reduction from 7 to 4, which moves the task from "immediate intervention required" to a lower risk level, where further observation is sufficient.

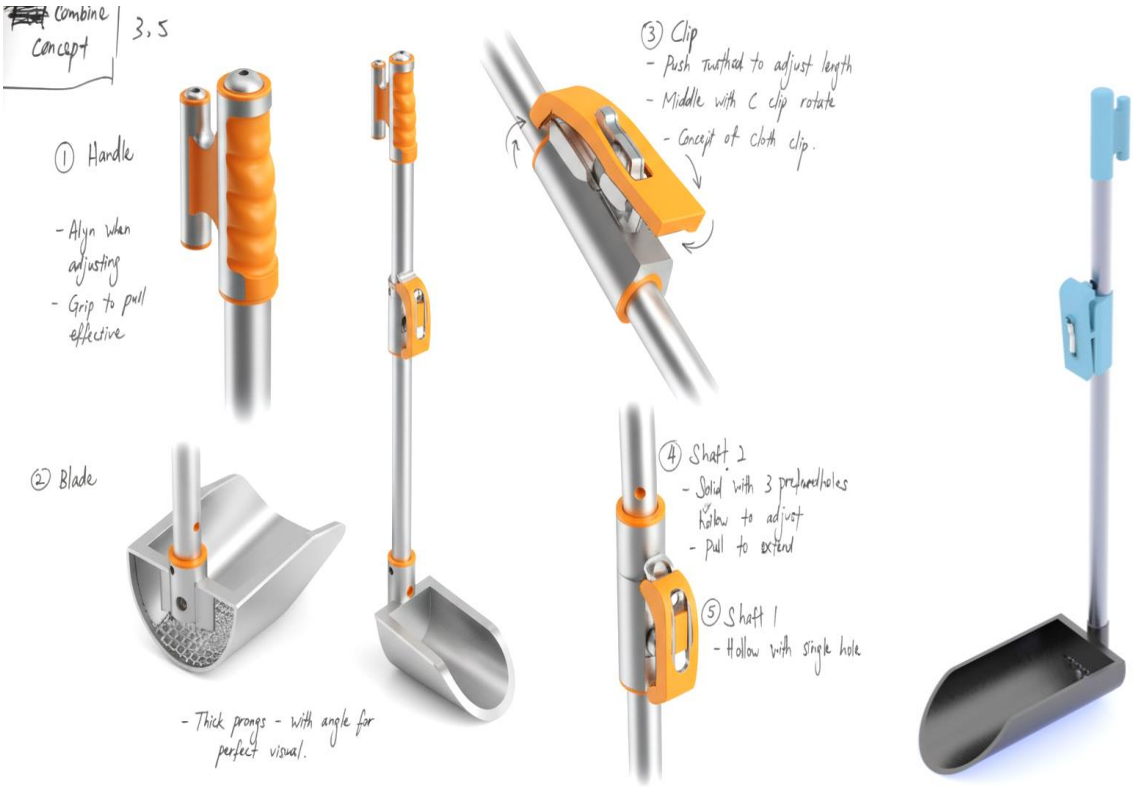

Figure 11. Final concept of gutter cleaning tool

4. CONCLUSION

This study successfully developed an ergonomic gutter cleaning tool (Concept 2+) designed to mitigate the high musculoskeletal risks associated with manual roadside drain maintenance. Initial ergonomics assessments, including RULA and CMDQ, revealed critical biomechanical stress on the hands, wrists, shoulders, and neck, with overall RULA scores reaching the highest action level (Score 7). These findings underscore an urgent need for intervention due to repetitive manual handling and non-neutral postures. The final design addresses these deficiencies by integrating an adjustable aluminum handle (154-169 cm) with a secure twist-lock mechanism to minimize excessive bending, and an optimized, lightweight ABS scoop to improve debris collection efficiency. Preliminary simulated evaluations of this hybrid concept indicate a significant improvement in ergonomic performance, specifically a projected reduction in RULA scores from 7 to 4 by correcting trunk and wrist alignment. This indicates a significant improvement in user comfort while maintaining high manufacturability. While this study

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provides a theoretical and simulated validation of ergonomic improvement, future research will involve physical prototyping and field-based reassessment using CMDQ and RULA to empirically confirm the reduction in cumulative trauma disorders. Consequently, the implementation of this redesigned tool is expected to reduce the prevalence of work-related musculoskeletal disorders among sanitation workers, ultimately enhancing operational efficiency and worker well-being in residential drainage maintenance.

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