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REVIEW ARTICLE



Additive manufacturing of lower-limb prosthetic sockets: a scoping review with a focus on multi-material approaches

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ABSTRACT

Purpose: Additive manufacturing (AM) is increasingly applied to lower-limb prosthetic sockets, offering faster production, lower cost, and improved customisation. Multi-material additive manufacturing (MMAM) enables rigid and flexible regions to be combined in a single socket, potentially improving load distribution and user comfort. However, research on MMAM remains limited and is distributed across engineering, biomechanical, and clinical disciplines.

Materials and Methods: A scoping review was conducted following PRISMA-ScR guidelines. Five databases (PubMed, Scopus, IEEE Xplore, Web of Science, and EBSCO) were searched for English-language publications from 2010 to 2024. Studies reporting the use of AM in the fabrication of lower-limb prosthetic sockets were included. Data were extracted and synthesised through thematic categorisation.

Results: Forty-six studies met the inclusion criteria. Five themes were identified: mechanical performance and structural enhancement ($n=18$), comfort and fit optimisation ($n=11$), AM parameter optimisation ($n=8$), comparisons with conventional sockets ($n=7$), and exploratory designs ($n=2$). Most research addressed mechanical reinforcement and parameter effects. MMAM applications remained largely at the prototype stage.

Conclusions: AM is a rapidly developing approach to lower-limb prosthetic socket fabrication. Evidence for MMAM remains preliminary, underscoring the need for standardised testing, reproducible workflows, and early clinical evaluation to support its translation into rehabilitation practice.

Additive manufacturing (AM) is increasingly applied to lower-limb prosthetic sockets, offering faster production, lower cost, and improved customisation. Multi-material additive manufacturing (MMAM) enables rigid and flexible regions to be combined in one socket, potentially improving load distribution and user comfort. However, research on MMAM remains limited and distributed across engineering, biomechanical, and clinical research. A scoping review was conducted following PRISMA-ScR guidelines. Five databases (PubMed, Scopus, IEEE Xplore, Web of Science, and EBSCO) were searched for English-language publications from 2010 to 2024. Studies reporting AM in the fabrication of lower-limb prosthetic sockets were included. Data were extracted and synthesised using thematic categorisation. Forty-six studies met the inclusion criteria. Five themes emerged: mechanical performance and structural enhancement ($n=18$), comfort and fit optimisation ($n=11$), AM parameter optimisation ($n=8$), comparisons with conventional sockets ($n=7$), and exploratory designs ($n=2$). Most research focused on mechanical reinforcement and parameter effects, while MMAM applications remained largely at the prototype stage. AM is a rapidly developing approach to lower-limb prosthetic socket fabrication. Evidence for MMAM remains preliminary, highlighting the need for standardised testing, reproducible workflows, and early clinical evaluation to support translation into rehabilitation practice.

Abbreviations: ABS: Acrylonitrile Butadiene Styrene; AM: Additive Manufacturing; CAD: Computer-Aided Design; CF: Carbon Fibre; FFF: Fused Filament Fabrication; ISO 10328: International Organisation for Standardisation for lower-limb prostheses; MMAM: Multi-Material Additive Manufacturing; PA-12: Polyamide-12; PC: Polycarbonate; PETG: Polyethylene Terephthalate Glycol; PLA: Polylactic Acid; PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews; RL: Residual Limb; SLS: Selective Laser Sintering; TF: Transfemoral; TT: Transtibial

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1. Introduction

In 2017, approximately 57.7 million people worldwide were living with limb amputations due to traumatic causes [1]. In the United States alone, an estimated 150,000 lower-limb amputations are performed annually [2]. For these individuals, prosthetic devices are essential for restoring mobility and independence [3,4].

A lower-limb prosthesis typically consists of a socket, knee joint (for above-knee amputations), pylon, and foot. The socket is the critical interface connecting the residual limb (RL) to the prosthesis [5]. Unlike an intact limb, where weight is transmitted through the skeletal structure, amputees rely on soft tissues of the RL to transfer forces to the rigid materials of the prosthesis [6]. The socket must therefore provide secure load transfer while minimising discomfort and tissue damage [7].

Socket fit is a major determinant of comfort and function. Poorly fitted sockets can cause skin breakdown, deep tissue injury, and impaired mobility [8–11]. Certain areas of the transtibial RL, such as the patellar tendon and popliteal depression, tolerate higher loading, while bony prominences such as the distal fibula are pressure-sensitive (Figure 1) [12]. Excessive loading in these areas reduces comfort and increases the risk of tissue damage [13], which may discourage prosthesis use [14,15].

Traditional socket fabrication involves casting the residual limb to create a positive mould, producing a check socket from thermoplastic, and then fabricating a laminated definitive socket [16]. This multi-step process is labour-intensive, wasteful, and highly dependent on the prosthetist's expertise [17]. Socket fabrication can take weeks or months, delaying rehabilitation and limiting access to care [18].

Advances in additive manufacturing (AM) have transformed prosthetic design and production. AM enables customisation, rapid prototyping, reduced waste, and enables cost-effective fabrication of prosthetic sockets [19–21]. Importantly, AM has the potential to reduce the global imbalance in access to

prostheses by providing affordable alternatives for amputees in resource-limited settings [22,23].

Multi-material additive manufacturing (MMAM) extends these benefits by enabling the integration of materials with different mechanical properties into a single socket. This approach allows for the strategic placement of rigid and flexible regions, aligning socket stiffness with anatomical loading requirements [24]. Such designs may enhance comfort, reduce interface pressures, and improve prosthesis usability.

Despite the growing application of AM in prosthetic socket fabrication, existing research is distributed across engineering, medical, and biomechanical fields, with limited synthesis of current practices and challenges. Research on MMAM for prosthetic socket design remains at an early stage, with most studies limited to prototype development or proof-of-concept demonstrations. To date, no comprehensive review has mapped the scope of this emerging field.

This review, therefore, maps the available literature on AM lower-limb prosthetic sockets, with particular attention to the emerging role of MMAM. Given the small number of studies on MMAM, the review aims to characterise the current stage of development rather than evaluate clinical effectiveness. It also aims to identify gaps that may guide future research.

2. Methods

A scoping review was conducted to map the literature on AM and MMAM in lower-limb prosthetic sockets. This review followed the methodological framework proposed by Arksey and O'Malley [25], further refined by Levac, Colquhoun [26], and was reported in accordance with the PRISMA extension for Scoping Reviews (PRISMA-ScR) guidelines [27]. The study selection process is illustrated in a PRISMA flow diagram (Figure 2), and the PRISMA-ScR checklist is provided as [supplementary material](#).

2.1. Research question

The review was guided by the question: "What is the current status of the literature on the utilisation of additive manufacturing in the fabrication of lower-limb prosthetic sockets?"

2.2. Objectives

The objectives were to [1]: map and synthesise research on AM in lower-limb prosthetic sockets [2], identify the technologies, Computer Aided Design (CAD) systems, and materials used, and [3] highlight gaps and future directions, particularly for MMAM.

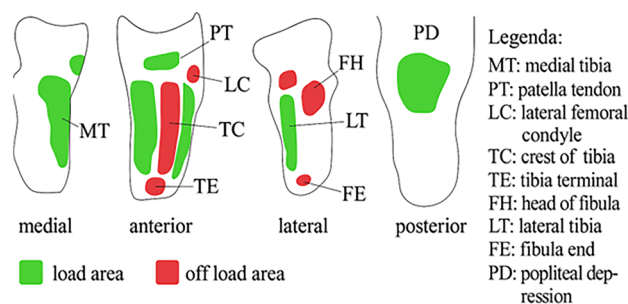


Figure 1. Anatomical zones of transtibial residual limb [12].

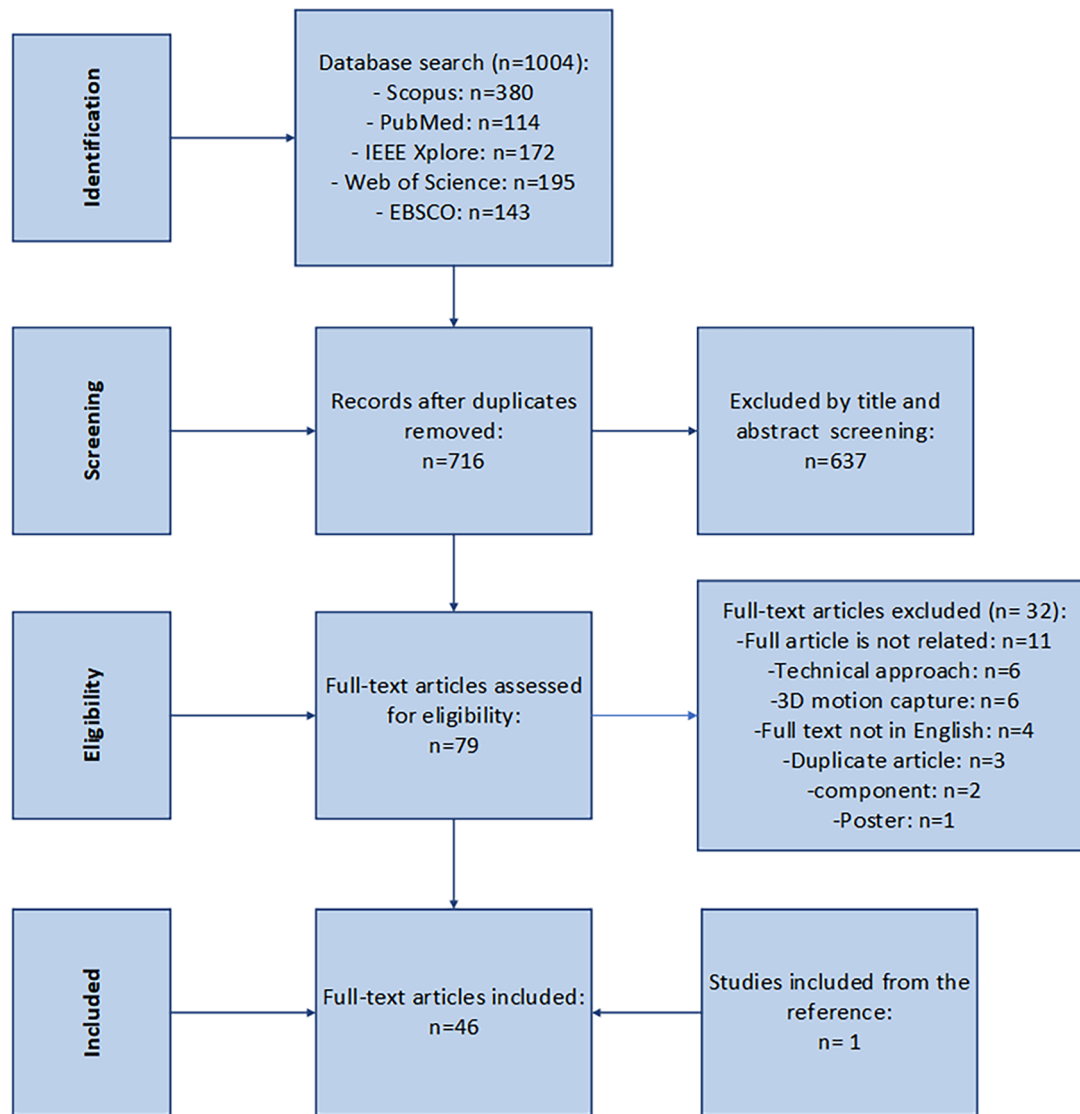


Figure 2. PRISMA flow diagram of study selection.

Table 1. Eligibility criteria used for study selection.

Criterion	Included	Excluded
Topic focus	Studies reporting AM (3D printing) of lower-limb prosthetic sockets	Studies focusing only on other prosthetic components (e.g., knee joints, prosthetic feet, suspension systems, pylons, adapters)
Study design	Experimental studies, simulation studies, prototype development	Review articles, editorials, commentaries
Publication type	Peer-reviewed journal articles and conference papers	Non-accessible publications
Language	English	Non-English
Accessibility	Full text accessible through institutional subscriptions	Studies without accessible full text

2.3. Inclusion and exclusion criteria

Studies were included if they reported on the use of AM in the fabrication of lower-limb prosthetic sockets.

Studies focusing solely on other prosthetic components (e.g., suspension systems, knee joints, prosthetic feet, pylons, or adapters) were excluded, as were review articles, commentaries, and editorials.

No restriction was placed on study design, allowing the inclusion of experimental, simulation-based, and prototype development studies. Studies that were not accessible through the authors' institutional subscriptions were excluded. The full eligibility criteria are summarised in Table 1.

2.4. Search strategy

A comprehensive search was conducted across five electronic databases: PubMed, Scopus, IEEE Xplore, Web of Science, and EBSCO. The search covered publications from January 2010 to October 2024, with the final search performed in October 2024.

The search strategy combined three groups of keywords relating to prosthetic devices, lower-limb descriptors, and additive manufacturing technologies. Boolean operators (AND, OR) were used to combine these terms. Truncation symbols (*) were applied to capture variations of key terms.

An example of the search string used in PubMed is provided below:

("prosthesis*" OR "artificial limb" OR "prosthetic socket" OR "socket")

AND

("lower limb" OR "lower extremity" OR "transfemoral" OR "above-knee" OR "transtibial" OR "below-knee")

AND

("additive manufactur*" OR "3D print*" OR "three dimensional print*" OR "digital fabrication")

Search strategies were adapted as necessary for each database according to its indexing system and search interface. Only English-language publications were included, and no restriction was placed on study design. The full database search strategies are provided in Appendix A.

2.5. Study selection

Study selection was conducted in two stages. First, titles and abstracts retrieved from the database searches were screened to identify potentially relevant studies. Articles that appeared to meet the inclusion criteria were then assessed through full-text screening.

Screening and eligibility assessment were performed by one reviewer (S.A.). When uncertainties arose regarding study eligibility, these were discussed with co-authors to ensure consistency in the application of the inclusion criteria. The study selection process is summarised in the PRISMA flow diagram (Figure 2).

2.6. Data charting

Data from the included studies were extracted into structured tables to support synthesis and comparison of study characteristics. Extracted information included author, year of publication, country, publication type, study objectives, socket type, additive manufacturing technology, materials used, software tools, outcome measures, and key findings.

Data extraction was conducted by one reviewer (S.A.) using a standardised data extraction table developed for this review. The extracted dataset is summarised in Appendix B, which presents the main characteristics of the included studies.

2.7. Synthesis of results

The findings are presented in three main sections (1): an overview of the included studies (2), the thematic categorisation of AM sockets, and (3) an analysis of the AM technologies and materials used. Given the substantial variation among included studies in methodology, objectives, and reporting, this review does not evaluate individual study findings. Instead, it provides a broad synthesis of the current research landscape.

3. Results

3.1. Overview of included studies and research trends

A total of 46 articles published between 2013 and 2024 were included. The search covered publications from January 2010 to October 2024, with the earliest eligible study identified in 2013. Most were peer-reviewed journal articles ($n=32$), complemented by 14 conference papers. Publication activity increased steadily after 2018 (Figure 3).

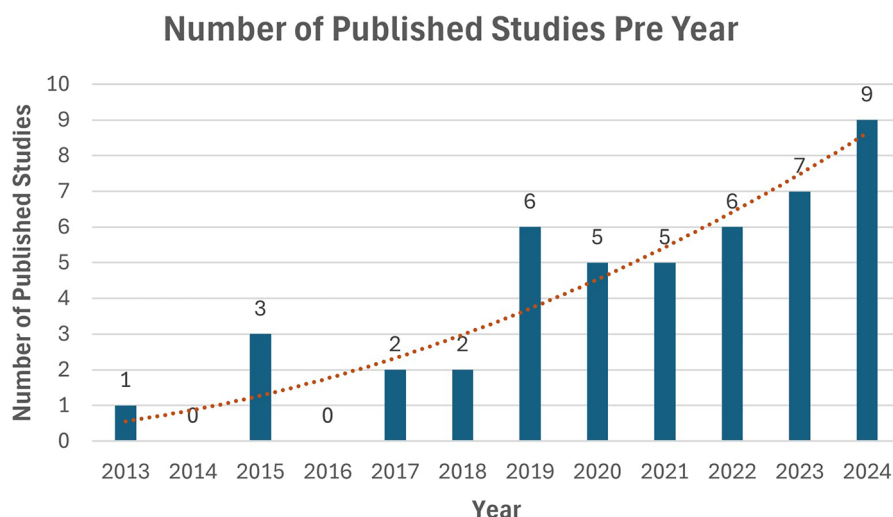


Figure 3. Number of publications on AM prosthetic sockets between 2013 and 2024.

Research originated from diverse geographical regions. The USA contributed the largest number of studies ($n=10$), followed by the United Kingdom, India, and Italy, with additional contributions from both high- and low-resource countries. Most studies focused on transtibial sockets ($n=31$), whereas trans-femoral sockets were less frequently investigated ($n=15$).

3.2. Thematic categorisation

The included studies were categorised based on their primary research focus into five themes (Figure 4): mechanical performance and structural enhancement ($n=18$), comfort and fit optimisation ($n=11$), AM parameter optimisation ($n=8$), comparative analysis with conventional sockets ($n=7$), and exploratory socket designs ($n=2$). These themes reflect the main technical challenges addressed in the field: improving structural reliability, optimising manufacturing parameters, and enhancing the biomechanical interaction between the socket and the residual limb.

3.3. Mechanical performance and structural enhancement ($n=18$)

Work in this area addressed the known mechanical limitations of printed polymers and explored strategies to increase strength, fatigue resistance, and structural reliability.

Fibre-reinforced sockets ($n=8$). Studies investigated the integration of carbon and natural fibres within polymer matrices such as PLA or Acrylonitrile Butadiene Styrene (ABS) [20,28–34]. Improvements in tensile performance, stiffness, and damage tolerance were generally reported compared with unreinforced sockets, though the magnitude of mechanical gains varied with fibre type and volume fraction.

Post-processing reinforcements ($n=1$). One study evaluated treatments and coatings, including carbon fibre, Kevlar, fibreglass, and cement layers, applied to printed sockets as post-processing reinforcements [35]. The treated sockets showed increased strength and improved surface durability.

Evaluation of mechanical properties ($n=9$). Finite element analyses and experimental tests, including tension, compression, and fatigue loading, were used to evaluate socket performance and identify failure modes [5,36–43]. AM sockets were generally reported to withstand typical loading conditions, though failure often initiated at the distal end or trimline regions.

3.4. Comfort and fit optimisation ($n=11$)

Studies in this category targeted the socket–residual limb interface, aiming to redistribute pressure, enhance anatomical conformity, and enable adaptive fit.

Variable stiffness sockets ($n=7$). These studies used MMAM to create region-specific flexibility by incorporating softer materials in pressure-sensitive zones and

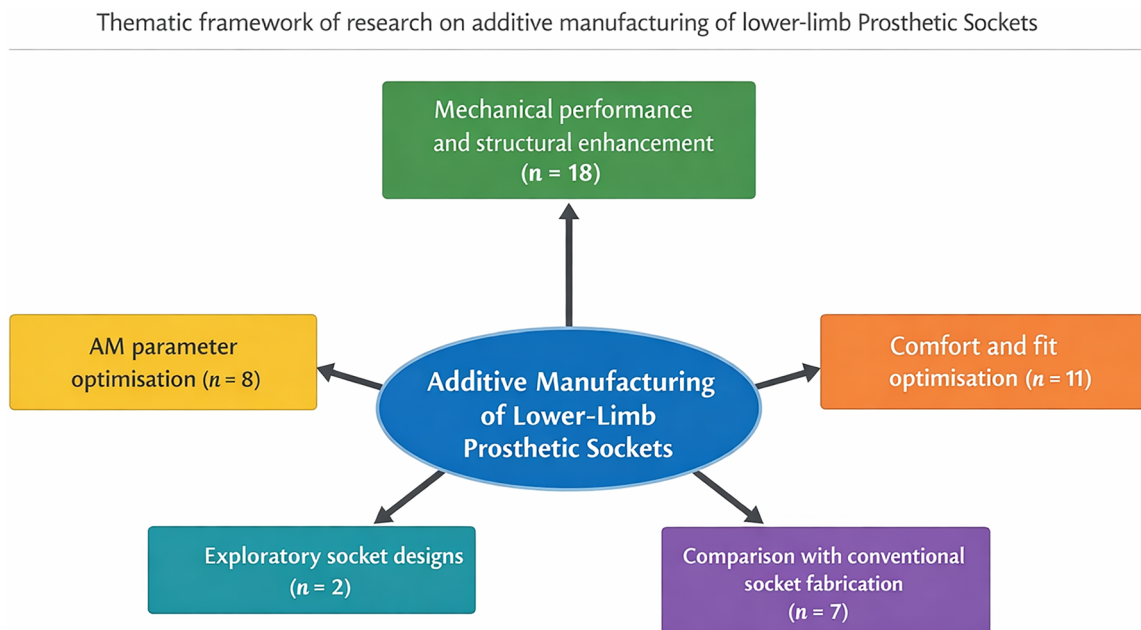


Figure 4. Thematic framework of research on additive manufacturing of lower-limb prosthetic sockets. The included studies were categorised into five primary research themes representing the main technical directions investigated in the literature.

stiffer materials in load-bearing regions [24,44–49]. Finite element analysis and pressure mapping showed improved pressure distribution and reduced localised stress in several of these studies.

Lattice structures ($n=2$). Bio-inspired lattice designs were explored to improve stress distribution across the socket–limb interface [50,51]. Simulation results indicated that lattice-integrated regions reduced peak stresses while maintaining an acceptable range of deformation.

Adaptive concepts ($n=2$). Two prototype studies explored adaptive socket fitting: one used air bladders to reduce interface pressure during the stance phase [52], and the other employed shape-memory structures for thermally driven, reversible shape adaptation [53]. Both approaches showed feasibility at the conceptual stage.

3.5. AM parameter optimisation ($n=8$)

Print settings, including infill density, layer height, nozzle size and build orientation, had a marked effect on manufacturability and mechanical reliability. Several studies identified settings that improved strength-to-weight ratios or reduced print time, while custom path planning showed notable gains in interlayer bonding and ultimate load [54–61]. Given differences in machines, materials, and socket geometries across studies, parameter guidelines are not yet generalisable.

3.6. Comparative analysis with conventional socket ($n=7$)

Comparative studies evaluated structural performance, cost, weight, production time, and user-reported outcomes relative to laminated or thermoplastic sockets. Several AM sockets met ISO 10328 structural testing requirements or demonstrated comparable performance under specific conditions, often with advantages in fabrication time, cost, and mass [62–68]. However, durability under high loads or extended use varied, underscoring the need to match fabrication methods to the clinical context.

3.7. Exploratory socket designs ($n=2$)

Two studies explored design concepts not readily achievable through traditional fabrication: integrated cooling channels to address heat and moisture management [69], and a monocoque construction combining socket, pylon, and foot in a single printed structure [70].

3.8. AM technologies, materials, and software used

The reviewed studies employed various AM technologies for fabricating prosthetic sockets. FFF was the most commonly used AM technology (35 of 46 studies), followed by PolyJet printing ($n=5$) and Selective Laser Sintering (SLS; $n=3$). Three studies did not report the printing technology used. The prevalence of FFF likely reflects its affordability, accessibility, and compatibility with a broad range of thermoplastics.

The reviewed studies employed a range of materials for fabricating AM prosthetic sockets. PLA was the most frequently reported material, followed by its reinforced variants: carbon fibre-reinforced PLA (PLA-CF), natural fibre-reinforced PLA (PLA-NF), and PLA combined with multi-walled carbon nanotubes (PLA-MWCNTs). Other reported materials included Polyamide-12 (PA-12), carbon fibre-reinforced nylon (CFRN), ABS, polyethylene terephthalate glycol (PETG), and polycarbonate (PC). A smaller number of studies employed multi-material combinations—typically VeroWhite (VW) and TangoBlack (TB) or rubber-like materials—to provide variable stiffness in specific socket regions. A few studies did not report the materials used.

A range of software tools were used across the digital workflow. For CAD modelling, SolidWorks (Dassault Systèmes, France) was the most frequently reported ($n=10$), followed by Meshmixer (Autodesk Inc., USA; $n=7$) for mesh editing, and Ultimaker Cura (UltiMaker B.V., Netherlands; $n=8$) for slicing and print preparation. Several studies used multiple tools in combination.

4. Discussion

This scoping review synthesised 46 studies on the use of AM in the fabrication of lower-limb prosthetic sockets. The reviewed literature is primarily driven by engineering challenges: improving the structural reliability of printed sockets, refining manufacturing parameters, and addressing the biomechanical interaction between the socket and the residual limb. The bulk of published work addresses mechanical performance through reinforcement strategies and numerical modelling, while fewer studies explore clinical outcomes, long-term durability, or patient experience. MMAM represents a notable development in this field, as it allows region-specific stiffness control that may improve load distribution across the residual limb. However, most reported designs remain at the prototype or proof-of-concept stage [20,34,42]. Further mechanical validation and clinical evaluation are needed before routine adoption in practice.

4.1. Structural performance and mechanical reliability

A substantial portion of the reviewed literature focuses on the mechanical performance of AM prosthetic sockets. The inherent limitations of commonly used thermoplastics in extrusion-based printing, particularly weak interlayer bonding and mechanical anisotropy, have driven research into reinforcement strategies. Carbon fibres, natural fibres, and composite reinforcements integrated within polymer matrices have been shown to improve tensile strength and structural durability relative to unreinforced materials [28–33]. Post-processing approaches, including surface coatings of carbon fibre, Kevlar, and fibreglass, have also been reported to increase socket strength [35].

Experimental and numerical studies frequently identified failure at regions of stress concentration, particularly near the distal end and trimline of the socket [5,38,40]. These observations point to the importance of accounting for socket geometry and load distribution during the design phase. While some AM sockets have demonstrated performance comparable to conventionally fabricated sockets under controlled conditions [63,67,68], variability in testing protocols makes direct comparison across studies difficult [71].

5. Materials and reinforcement strategies

PLA and its reinforced variants were the most frequently reported materials, likely because they are affordable, widely available, and compatible with most desktop FFF printers. Carbon fibre reinforcement of PLA increased flexural strength by up to 30% in one study [33], while PLA combined with multi-walled carbon nanotubes achieved the highest flexural strength among the composites tested [31]. Polyamide-based materials and carbon fibre-reinforced nylon were used in studies requiring higher load-bearing capacity [34], but these materials typically require SLS or industrial-grade equipment that is less accessible.

Across the reviewed studies, material choice often appeared to be guided by printer compatibility rather than by a systematic assessment of biomechanical requirements. Few studies provided an explicit rationale for their material selection or evaluated candidate materials against the loading conditions specific to prosthetic sockets. Future work in this area would benefit from comparative testing of materials under standardised prosthetic loading protocols such as ISO 10328 [72].

5.1. Digital limb capture and socket design workflows

Several of the reviewed studies used digital methods to acquire residual limb geometry, including optical scanning, photogrammetry [64], and medical imaging such as MRI [44]. These approaches generate patient-specific three-dimensional models that can be modified in CAD software before fabrication, offering advantages over traditional plaster casting in terms of repeatability and the ability to apply computational design adjustments.

In practice, however, the digital workflow is not yet fully automated. Socket design modifications in many of the reviewed studies still relied on manual input from a prosthetist [45–47]. Challenges also remain around scanning accuracy and soft tissue deformation during data acquisition. One study used MRI to capture both external geometry and internal tissue properties of the residual limb, enabling a stiffness map that informed socket design [44], an approach not replicated in subsequent work. The gap between digital capture and biomechanically informed design suggests that integrating scanning data with tissue modelling and automated design tools is a priority for future development.

5.2. Manufacturing parameters and process reliability

Manufacturing parameters had a substantial influence on socket performance across the reviewed studies. Infill density was the most frequently investigated variable; higher densities improved structural strength but at the cost of increased print time and material use. One study reported that 60% infill offered the best balance of strength and efficiency for a PLA socket [55], although this finding is specific to the material and printer used.

Build orientation and deposition path also affected mechanical behaviour. Extra-wide filament deposition increased socket strength by 48% while reducing print time by 67%, primarily by improving interlayer bonding [57]. Optimised printing paths raised maximum load capacity by 75% in another study [58]. These results indicate that the print strategy, not only the material choice, has a significant bearing on whether an AM socket meets structural requirements.

A related concern is dimensional accuracy. Geometric deviations introduced by layer misalignment or printer calibration can affect socket fit at the limb interface, with direct consequences for comfort and load distribution [56,59]. This issue has received less attention

than bulk mechanical properties in the reviewed studies but is likely to be important for clinical acceptability.

5.3. Comfort, fit, and biomechanical interface considerations

The seven MMAM studies identified in this review [24,44–49] all used multi-material printing to vary socket stiffness across different anatomical regions. The underlying principle is consistent: softer materials are placed over pressure-sensitive areas such as the fibula head, while stiffer materials are retained in load-bearing regions such as the patellar tendon and medial tibial flare. One early study reported a 15–17% reduction in interface pressure using a variable-impedance socket printed on a PolyJet system [44]. Later work developed iterative design workflows using pressure data to assign material stiffness zones, demonstrated through both FEA and physical prototypes [24,45–47]. More recently, voxel-level stiffness modulation guided by FEA-derived contact pressure maps has been explored [48].

Lattice-based designs offer an alternative route to local compliance. Simulation results showed that conformal lattice structures reduced peak stress by 35% compared with a plain socket wall [50], while different lattice topologies were explored to identify patterns offering a favourable balance between deformation and stiffness [51].

Despite these advances, the MMAM evidence base remains thin. None of the seven studies included standardised mechanical testing under ISO 10328 [72]. Only one study tested a socket on a human participant [44]. The remaining studies relied on FEA, bench-top evaluation, or prototype demonstration without clinical feedback. Whether the pressure reductions observed in simulation translate into meaningful improvements in comfort during daily activities remains uncertain. Establishing this link will require controlled trials that combine measurements of interface pressure with patient-reported outcomes.

5.4. Limitations of current AM technologies

FFF dominated the reviewed literature (35 of 46 studies), which has practical implications for the field. FFF is accessible and affordable, but the resulting parts exhibit anisotropic mechanical properties and weak interlayer adhesion, both directly relevant to the structural demands of prosthetic sockets [42,57]. PolyJet printing, used in five studies, enables multi-material fabrication at voxel-level resolution but requires substantially more expensive equipment. SLS, used in three studies, produces parts with more isotropic

properties but offers no multi-material capability in its current form. The concentration of research around FFF means that the evidence base is largely shaped by the constraints of one technology. Findings may not transfer directly to parts produced by other systems.

5.5. Mechanical testing and validation

Mechanical testing across the reviewed studies was inconsistent. Some studies applied ISO 10328 static and cyclic loading protocols [20,42,67,68], while others relied solely on FEA without experimental validation [37,40,61]. It should be noted that ISO 10328 is designed for the structural testing of complete lower-limb prosthetic assemblies rather than socket-specific performance [73], and no equivalent standard exists for the isolated testing of prosthetic sockets. The absence of a common testing framework for AM sockets therefore limits the ability to compare results across studies [71]. Among the studies that did apply ISO 10328, outcomes varied: one reported that a low-cost PLA socket withstood over 2 million load cycles [42], while another found that AM sockets had lower strength than laminated counterparts [63]. These contrasting results likely reflect differences in material, print settings, and socket geometry rather than a fundamental limitation of AM itself.

Fatigue testing and clinical evaluation remain scarce. Only a small number of studies tested sockets beyond static failure [5,20,42], and real-world trials involving prosthesis users were limited to a few comparative studies [65,66]. This gap between laboratory testing and clinical use is the most significant barrier to the adoption of AM sockets in routine practice.

5.6. Implications for prosthetic engineering and research

Taken together, the reviewed evidence points to three priorities for moving AM socket fabrication towards clinical use. First, the field needs a shared mechanical testing framework, ideally built around ISO 10328 [72], so that results from different studies can be meaningfully compared. Second, material selection should be driven by the biomechanical demands of the socket–limb interface rather than by printer compatibility alone; comparative studies testing multiple materials under identical conditions are currently lacking. Third, clinical evaluation must be integrated earlier in the development cycle. Most reviewed designs were tested only in simulation or on test rigs, with very few involving prosthesis users [65,66]. Comfort, usability, and durability as experienced by the wearer cannot be inferred from bench testing and will

require structured pilot trials bringing together engineers, prosthetists, and rehabilitation specialists.

6. Limitations

The limitations of this review are primarily related to the scoping review methodology and the nature of the available literature. As a scoping review, this study aimed to map the existing body of research rather than critically appraise study quality; no formal assessment of methodological quality or risk of bias was conducted. The findings should therefore be interpreted as an overview of research activity rather than an evaluation of the strength of evidence.

The included studies exhibited substantial variability in research objectives, experimental methods, materials, and testing procedures, which limited direct comparison and restricted the ability to draw conclusions about the relative performance of different AM approaches. Many studies focused on prototype development or simulation, with few reporting comprehensive mechanical validation or clinical evaluation. The available evidence is therefore preliminary, particularly for MMAM socket designs.

Although a structured search strategy was applied across five databases, some relevant studies may have been missed due to inconsistent terminology across the prosthetics and AM literature. Additionally, screening and data extraction were performed by a single reviewer, which may have introduced selection bias despite consultation with co-authors on uncertain cases.

7. Conclusion

This scoping review synthesised 46 studies on AM of lower-limb prosthetic sockets published between 2013 and 2024. Research activity has centred on improving the structural performance of printed sockets, with growing but still limited work on multi-material approaches that may improve comfort and fit. MMAM remains at the proof-of-concept stage, and no study to date has combined standardised mechanical testing with clinical evaluation of an MMAM socket. Advancing this field will require reproducible manufacturing workflows, shared testing protocols, and early-stage clinical trials that assess both structural reliability and patient-reported outcomes.

Authors' contributions

CRedit: **Sattam Alharbi**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing; **Philip**

Sewell: Supervision, Writing – review & editing; **Bryce Dyer**: Supervision, Writing – review & editing; **Abigail Batley**: Supervision, Writing – review & editing.

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