Efficient Three Dimensional Modelling of Additive Manufactured Textile Structures

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Abstract

Textile structures realised by Additive Manufacturing (AM) techniques have received increasing attention during the previous decade. Due to their potential to significantly improve upon both the geometric complexity and functionality available from conventional fibre-based textiles, AM textiles present a serious opportunity to design and develop novel solutions for conventional and high-performance textile applications. AM textiles also provide the capability to produce net-shape textile artefacts and allow the development of personalised, high-performance textiles from a variety of materials currently being processed by AM technologies.

While the motivation exists for the wider-scale adoption of these novel structures, practical access to an efficient three dimensional (3D) modelling strategy limits their applications. The research presented here discusses the issues surrounding the 3D modelling of complex AM textiles and discusses dedicated methodologies developed for the generation of their conformal data. The research culminates with a robust methodology for the generation of AM textile apparel data suitable for manufacture by AM techniques.

Introduction

Research in the area of Additive Manufactured (AM) textiles has mainly concentrated on the development of efficient modelling strategies for the creation of the three dimensional (3D) Computer Aided Design (CAD) data required for their manufacture by AM techniques [Bingham et al 2007, Bingham 2007]. However, additional research has also been undertaken to address their mechanical properties, design and possible applications of these novel, complex structures [Crookston et al 2008, Johnson et al 2011]. Most recently, research has been undertaken to successfully design and manufacture AM textiles capable of attaining the British level one standard for stab-resistance [Johnson et al 2012]. While a genuine motivation exists for the further development of AM textile applications, efficient modelling of conformal and net shape AM textile artefacts remains a significant issue.

Modelling AM textiles with CAD

The modelling of individual AM textile link structures using currently available 3D CAD systems is relatively simple for expert users and complex geometric designs can be generated with relative ease. The use of CAD systems can be expanded further for the generation of planar samples of AM textile using a simple planar ‘Array’ or ‘Patterning’ function, common to most current CAD systems. Planar samples can be generated as either quadrilateral-based or triangular-based patterned arrays as demonstrated in Figure 1.

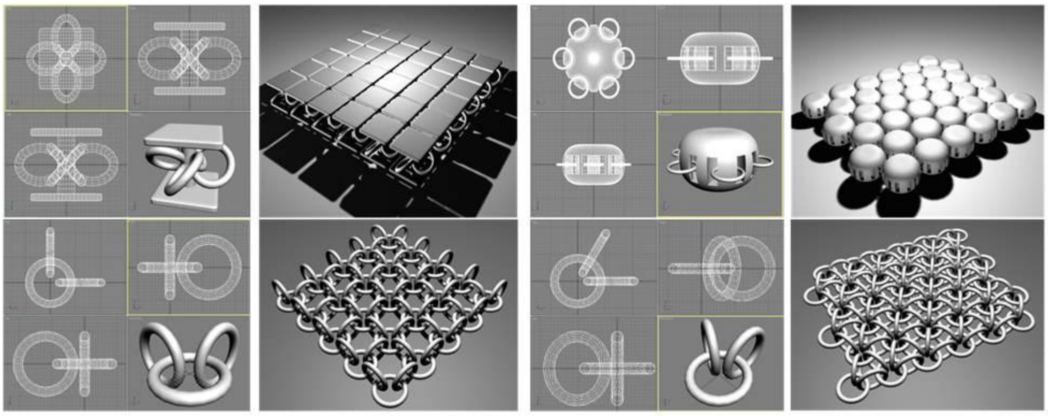

Figure 1: AM textile samples, Left - quadrilateral-based, right - triangular-based

The limitations associated with current CAD systems relate to the capability of generating conformal or net-shape AM textile artefacts. While it is possible to generate simple net-shape AM textiles (e.g. cylindrical), the generation of more complex net-shapes, such as hemispherical samples, is problematic and can result in incorrect tessellation of the individual link structures, also demonstrated in Figure 2.

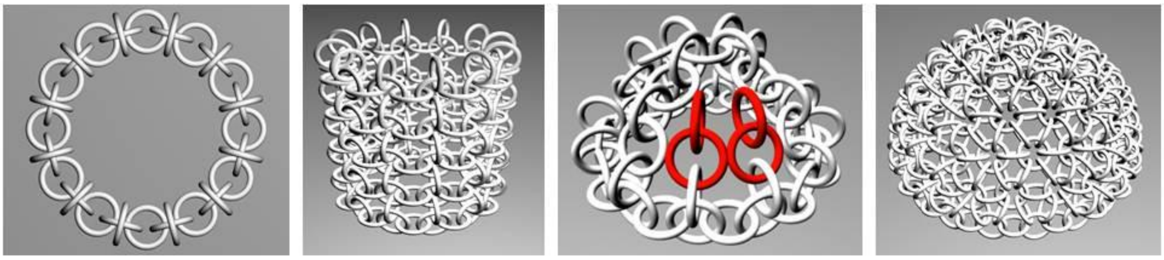

Figure 2: Cylindrical and hemispherical AM textile samples

Further investigation revealed the generation of a hemispherical AM textile sample could only be achieved through the use of a triangular-based AM textile link configuration (instead of a quadrilateral-based) and the acceptance of dimensional variance within the individual link structures. The modelling of the hemispherical AM textile sample demonstrated in Figure 2 also required a significant amount of manual manipulation by the CAD user and was therefore laborious, error prone and inefficient. While this can be tolerated for smaller net-shaped AM textile artefacts, the modelling of larger AM textile structures, for example apparel, would be impractical.

In reality, an individual textile link structure can be designed with an extremely high level of geometric complexity. However, this initial experimental modelling demonstrates the difficulty encountered when attempting to combine these links into conformal or net-shape AM textile structures. In this case, the requirement is not the creation of a singular or linear and circular array of complex individual geometries, but the automated creation of a uniformly distributed collection of complex geometries, potentially numbering in the thousands, that ultimately create the hierarchy of a conformal AM textile structure. As complex (double curvature) geometries cannot be accurately described by any simple array or patterning function within current CAD systems and no automated mapping function currently exists to replace the required manual manipulation of individual link geometries, the generation of conformal AM textile data is currently severely restricted. The work presented here has developed a novel approach to reduce these restrictions, allowing complex AM textile structures to be modelled quickly and efficiently.

AM textile modelling strategy

In order to unlock the potential of conformal AM textiles and provide practical access to the efficient generation of AM textile data, a dedicated modelling strategy is required, with specific constraints:

- Provide an efficient means of generating complex conformal AM textile data suitable for manufacture by AM techniques
- Attempt to maintain uniformity within the dimensions of the individual AM textile link structures
- Remove the need for manual intervention by the user for the positioning of the individual AM textile link structures

Uniformity within the final AM textile structure is desirable due to manufacturing constraints and the potential relationship between geometry (size, shape) and functionality when considering high-performance AM textile structures [Bingham 2007]. Major dimensional variation within the individual AM textile links could result in either a failure to build (the links being too small, highly deformed or touching another link) or failure to perform as designed (scale, shape and functionality). Observations from experimental modelling using current CAD systems has highlighted the efficiency of using an array or patterning function to describe the intended locations of individual link geometries and repeating the original link geometry to those intended locations, as demonstrated in Figure 3, creating the final AM textile structure.

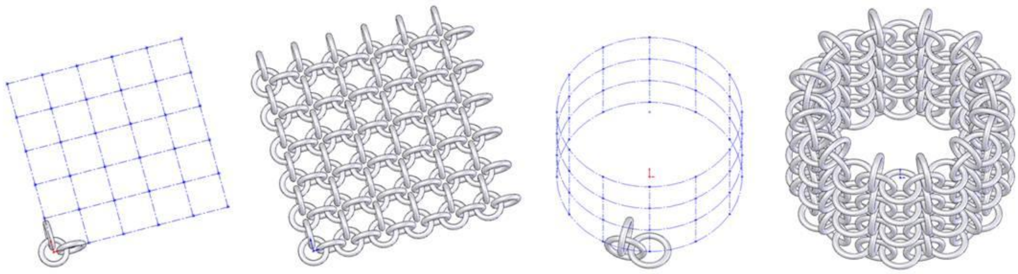

Figure 3: Array functioning (quadrilateral-based)

An efficient modelling strategy can therefore be defined as an approach that removes the requirement of any manual intervention of the AM textile link structures by the CAD user and accurately controls their location and spacing by automated mapping of the individual geometries. Repeating the original link structure also removes any potential for dimensional variance within the resultant AM textile. The intended locations of the individual links (shown as dashed lines) in Figure 3 can be considered as a surface mesh, representing the desired final configuration of the conformal or net-shape AM textile. This insight developed the idea of generating and utilising a 'mapping' surface mesh for the generation of conformal and net-shaped AM textiles. However, while the strategy of generating a surface mapping mesh is relatively simplistic for planar and cylindrical samples as demonstrated in Figure 3, the generation of a mapping mesh for complex topology is much more problematic.

Surface mapping mesh

The main requirement of the surface mapping mesh, when used as a means of providing locations over complex topology for the accurate positioning of AM textile link geometries, was a uniform structure and equidistant node spacing, demonstrated in Figure 4.

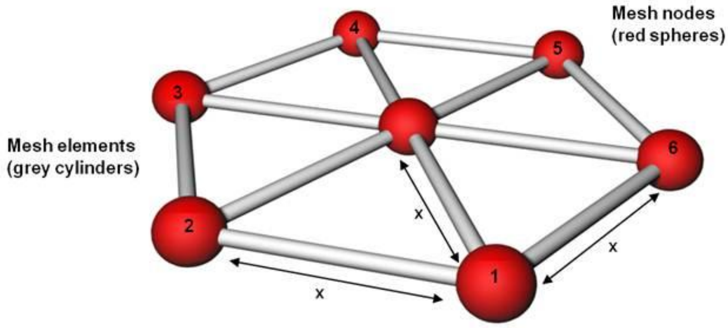

Figure 4: Idealised mapping mesh

For a surface mesh to exhibit such qualities, the only possible structure the mesh can be generated from, is a set of equilateral triangular elements. To clarify, if a section of a uniform and equidistant surface mesh is considered, as demonstrated in Figure 4, the structure of the mesh can be described through a system of nodes and elements. The nodes of the mesh, shown as red spheres in Figure 4, are locations from the intended topology that are described by the mesh. The elements of the mesh, shown as grey cylindrical geometries in Figure 4, are described as the geometry connecting the nodes of the mesh, completing the surface mesh structure. For the surface mesh to be uniform, each node contained within the mesh must be connected to a maximum of six other nodes in a triangular, hexagonal configuration. Also, for the mesh to be equidistant, the distance observed between each node, shown as **(x)** in Figure 4 must all be constant, and therefore, the elements of the mesh must all be equal length.

Various existing surface mesh generation algorithms were investigated for their application as a mapping mesh generator for AM textile data generation, including: Indirect or parametric space types [Marur 2005], Advancing front types [Borouchaki 2000], Direct and indirect sphere packing types [Shimada 1997]. Additionally, several commercially available Finite Element (FE) pre-processors were also explored, including: Fluent Gambit [Fluent 2011], MSC Patran [MSC 2011], ANSY [ANSY 2011] and Hypermesh [Hypermesh 2011]. However, it was quickly established that the generation of a completely uniform and equidistant mesh structure as demonstrated in Figure 5 was not possible. Modification of an existing surface mesh generation algorithm was also considered, however, given the exacting requirements of the uniform and equidistant mesh structure, it was decided that a dedicated surface meshing algorithm was required.

Further research was undertaken to achieve this aim and a new experimental surface meshing algorithm based on Sphere Packing [Shimada 1997] was developed by the author specifically for AM textile data generation [Bingham 2007]. The results of the research are demonstrated in Figure 5 for a range of topology, showing the desired uniform and tolerance-based (typically +/- 0.2units), equidistant mesh structure required when utilised as a mapping mesh for AM textile data generation. Having established a methodology for the generation of a suitable mapping surface mesh investigation into a robust geometry mapping methodology was required.

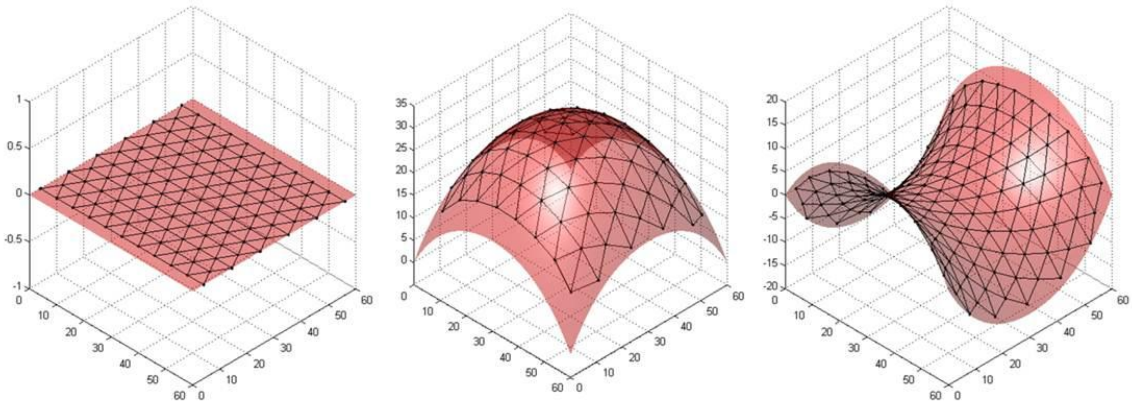

Figure 5: Example uniform and equidistant surface meshes

Development of a mapping tool for AM textile data generation

The initial 3D modelling of AM textile structures highlighted many limitations when generating conformal or net-shaped AM textiles and the requirement for a dedicated 3D modelling strategy or tool. However, it also reinforced the geometric complexity achievable when considering the design and 3D modelling of AM textile link structures and the efficiency of mapping to a predefined mesh. A requirement of any specifically developed modelling strategy for the generation of AM textile data must also provide this level of geometric complexity for the design and development of present and future AM textiles. It was therefore decided to incorporate the capabilities of 3D CAD systems into the modelling strategy by simply importing the 3D data they generate. Similarly, it was decided not to directly incorporate the surface meshing algorithm discussed previously into the methodology but supply the necessary data as a further input. These decisions simplify the requirements of a dedicated tool for the generation of conformal AM textile data into a system capable of mapping complex 3D data to an imported surface mapping mesh. The mapping methodology can be summarised in the following four stages:

- Stage one: Import CAD data of link geometry (input one) and surface mesh data of topology (input two)
- Stage two: Calculate surface normals at mapping locations from surface mesh
- Stage three: Orientate link geometry to match mapping locations of the surface mesh
- Stage four: Translate orientated link to mapping location

The four individual stages of the mapping methodology provide the core functionality of the developed AM textile modelling strategy. The entire AM textile modelling strategy can be summarised as follows:

1. Design individual AM textile link structure using conventional CAD software and export as STL data
2. Identify target surface topology for the final AM textile structure
3. Generate uniform and equidistant mapping mesh of target surface topology
4. Identify mapping locations (node and or element midpoints) and calculate surface normal from mapping mesh
5. Copy and orientate original AM textile link structure to match required surface normal at the mapping location while remaining at the global origin
6. Translate orientated AM textile link structure to mapping location
7. Repeat stages five and six until every mapping location has been utilised
8. Export final AM textile as STL data while omitting original AM textile link structure

The core mathematics underpinning this methodology is not discussed within this paper but is fully discussed in [Bingham 2007, Bingham 2012].

Experimental testing of the mapping methodology

To validate the capabilities of the documented methodology it was coded into a discrete software mapping tool [Nottingham 2006]. The software mapping tool has three key functions that required testing and validating:

- The ability to calculate the surface normal at the mesh nodes and element midpoints
- The ability to map complex geometry data described in STL format to the specified mapping locations without distortion or user intervention
- The ability to maintain the original rotational orientation of the mapped geometry

Successfully attaining these capabilities would therefore provide all the functionality required to efficiently generate conformal AM textile data.

Experiment one: Surface normal validation

The surface normal at any mesh node or element midpoint was calculated directly from the surface mesh and not the original geometry from which the mesh was created. To understand the effectiveness of the mapping tool in delivering this key capability, marker geometry, as demonstrated in Figure 6, was mapped to example surface meshes demonstrated in Figure 5. The marker geometry was designed to allow a visual inspection of the final generated data to be undertaken as the direction of the mapped arrow indicated the surface normal at each mapping location. Any anomaly with the surface normal calculation at the mapping locations was then easily detected through the visual inspection of the arrow directions of the resultant STL data. The mapping meshes, demonstrated in Figure 5, used for this experiment were:

- Planar mapping mesh: 60 units square with a 6 unit nodal spacing
- Domed (hemisphere approximation) mapping mesh: 60 units square with a 6 unit nodal spacing
- Saddle mapping mesh: 60 units square with a 6 unit nodal spacing

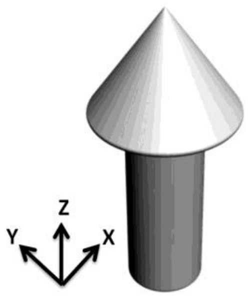

Figure 6: Marker geometry

Experiment one result

The marker geometry demonstrated in Figure 6 was mapped to both the nodes and element midpoints of the three example surface meshes. The resultant STL data generated was then imported into 3DS Max [Autodesk 2012] to visually inspect the positions of the marker geometry relative to the mapping locations and the surface normal calculated at each location. The results of nodal mapping for each of the three surface meshes are demonstrated in Figure 7.

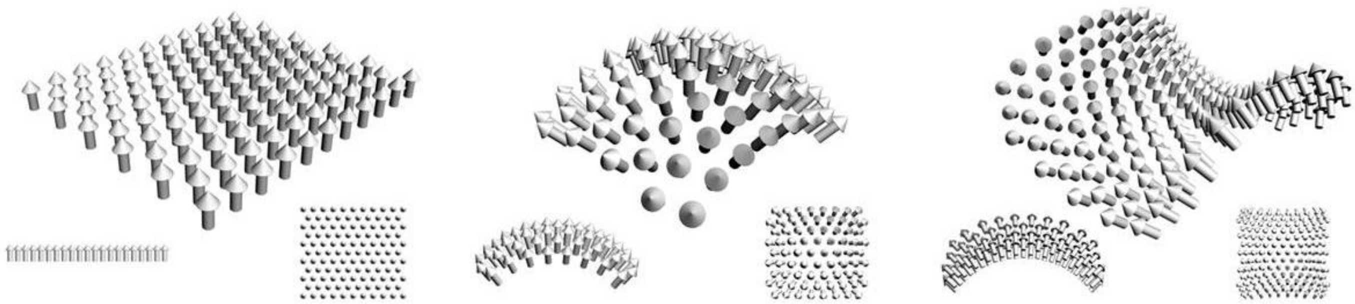

Figure 7: Experiment one, marker geometry nodal mapping

Figure 7 demonstrates that the orientation of the marker geometries reflect the expected surface normal at the nodal mapping locations of the three meshes utilised. For each mesh, the mapping tool positioned the marker geometry to the intended mapping locations (nodes and element midpoints) while also matching the expected surface normal, resulting in a smooth transition of arrow direction and reflecting the curvature of the intended surface geometry.

Experiment two: Complex geometry mapping validation

The second experiment was conducted to determine whether the mapping methodology was capable of mapping complex geometry without any distortion. Complex test geometry (Mobius knot) was utilised for this experiment as demonstrated in Figure 8. The test geometry, described as STL data, was mapped to each of the surface meshes detailed in experiment one (planar, dome and saddle), firstly to the nodes of the mapping mesh and then to the element midpoints.

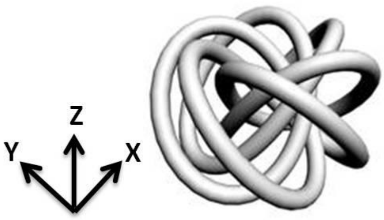

Figure 8: Experiment two test geometry, mobius knot

Experiment two result

The results of the mapping experiment to the nodes of the example domed mapping mesh are demonstrated in Figure 9. For all three surface meshes utilised, the mapping methodology was successful in mapping the geometry to the nodes and element midpoints of the mesh by modifying the orientation to the required surface normal without distorting the original geometry. The individual shell entities within the generated STL data were extracted and compared with the original input STL data, where no discernible differences were recorded.

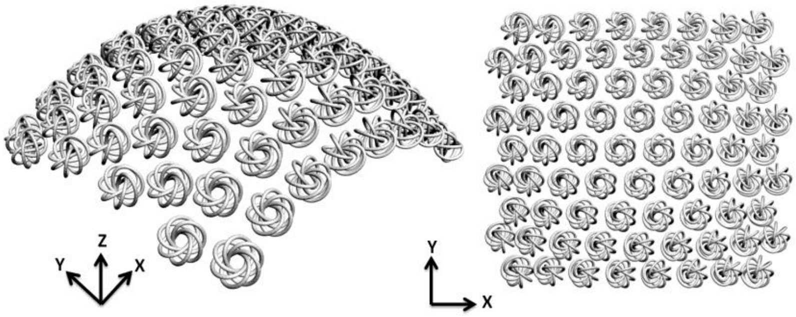

Figure 9: Experiment two nodal mapping to domed mesh

Experiment three: Rotational orientation validation

The third experiment was conducted to determine whether the original rotational orientation of the mapping geometry could be maintained within the final mapped geometries. Three asymmetrical test geometries were utilised for this experiment as demonstrated in Figure 10. Although identical, the rotational orientation (Cartesian axes) for each one was modified to produce a different final outcome:

- Teapot one: Spout orientated to the X axis
- Teapot two: Spout orientated to the Y axis
- Teapot three: Spout orientated to a combination of the X and Y axis

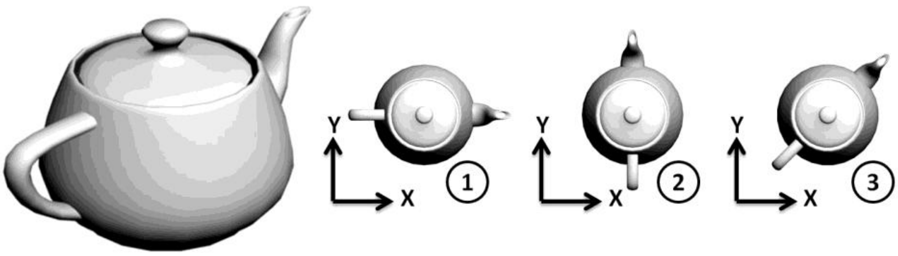

Figure 10: Experiment three test geometry orientations, teapot

The test geometries, described as STL data, were mapped to each of the surface meshes detailed in experiment one and two (planar, dome and saddle meshes), firstly to the nodes of the mapping mesh and then to the element midpoints.

Experiment three result

The results of the mapping experiment to the nodes of the example domed mapping mesh for all three test geometries are demonstrated in Figure 11, 12 and 13.

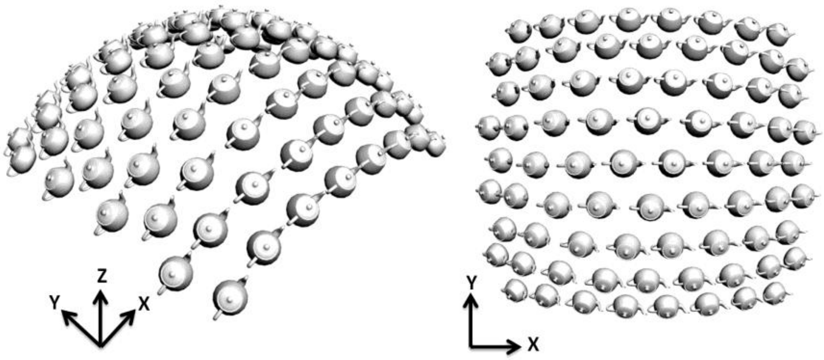

Figure 11: Experiment three, test geometry one, nodal mapping to domed mesh

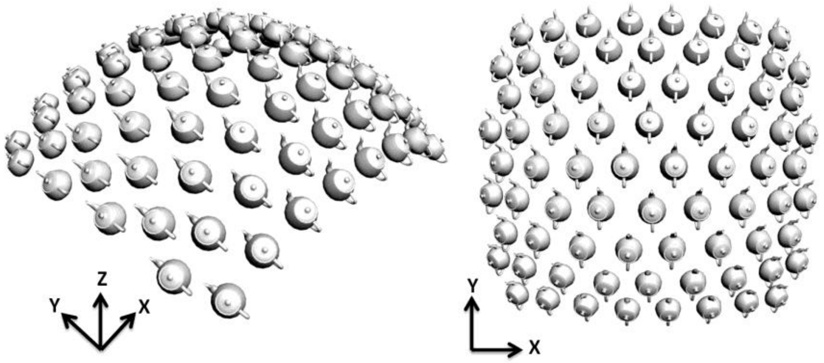

Figure 12: Experiment three, test geometry two, nodal mapping to domed mesh

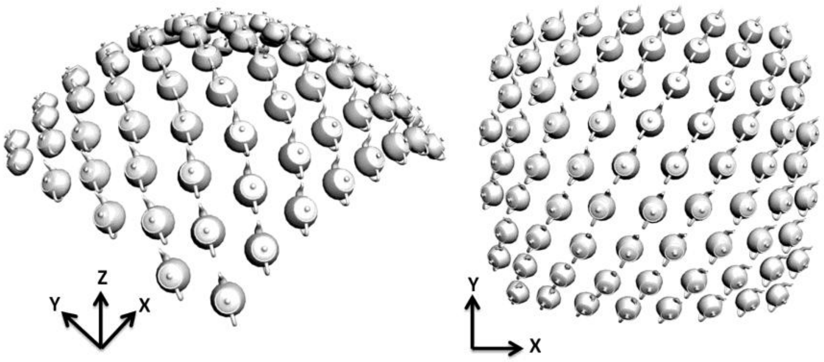

Figure 13: Experiment three, test geometry three, nodal mapping to domed mesh

For all three surface meshes utilised, the mapping methodology was successfully in mapping the geometry to the nodes and element midpoints of the mesh by modifying the orientation to the required surface normal without distorting the original geometry. A visual inspection of the generated data for each test geometry indicated that the mapping methodology was also successful in maintaining the original rotational orientation of the test geometries throughout the mapping process.

Discussion of experimental results

The results of the three validation experiments indicate that the mapping methodology developed has the capability to efficiently map complex geometry described as STL data to a surface mesh without any distortion, whilst also matching orientation to the surface normal at each location. These capabilities therefore provide all the functionality required for the efficient generation of conformal AM textile data. Through the application of a uniform and equidistant mapping mesh it is possible to efficiently generate complex and conformal AM textile data suitable for manufacture by AM techniques. The results of this process are demonstrated in Figure 14, where a 1unit spacing mapping mesh based on a 60 unit square saddle surface has been utilised for the generation of a conformal AM textile sample. The modelling process for this sample required no user intervention other than the input of the original textile link structure (simple torus) as STL data and the surface mesh data file. The final STL data as demonstrated in Figure 14 was generated in under 30 seconds.

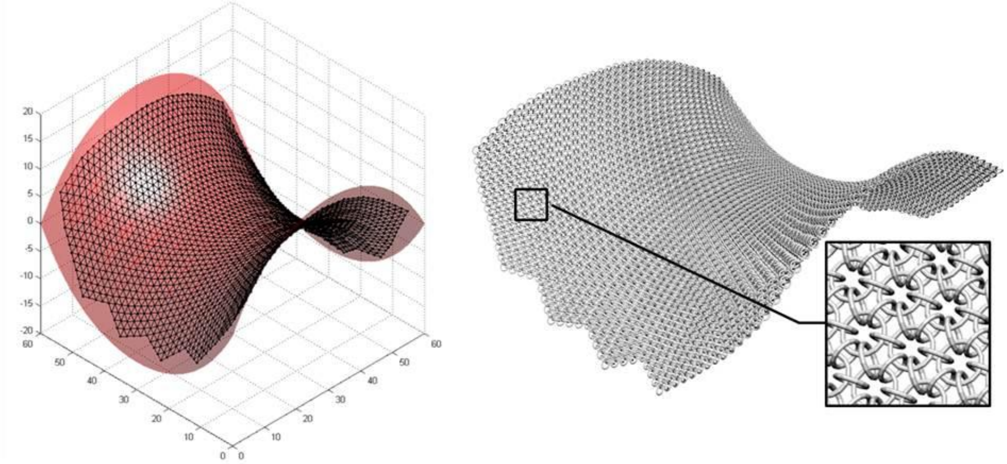

Figure 14: Conformal AM textile data generation using the developed mapping methodology

To validate the suitability of the data generated for manufacture by AM, the STL data was inspected within Materialise's Magics software [Materialise 2012]. The complete AM textile STL data structure was first modified so each individual link of the AM textile became a discrete part using the 'shells to parts' functionality of the software. Once complete, an interference check was performed between all parts to identify any interfering triangles of the STL data. The inspection revealed no interference within the entire structure and therefore suitable for manufacture by AM.

Limitations of the methodology

The demonstrated methodology, for the generation of conformal AM textile data, is robust, accurate and efficient. However, the quality and range of the data generated is dependent on the input mapping mesh, where any distortion or irregularity within the mapping mesh is directly replicated in the resultant data. The capabilities of the experimental surface meshing algorithm developed for this research are currently limited and can only generate uniform and equidistant (tolerance-based) mesh structures from mathematically described quadratic surface patches. The surface patches are described using five-point polynomial interpolation curves (splines) that form the four boundaries of each quadratic patch. The system requires the user to input five point (height) values for each side of the quadratic patch in order to generate a target topology (surface) that allows the creation of a uniform and equidistant mapping mesh structure. Additionally, the experimental meshing algorithm generates the uniform and equidistant mesh structure by 'mesh seeding' from the centre of the target surface and prevents full mesh coverage of the entire quadratic patch, as demonstrated in Figure 5 and 14. While the experimental meshing algorithm allowed the discussed mapping methodology to be developed and validated, the limitations of the meshing algorithm prevents practical access to a range of more complex topology and manifold objects that are required for present and future applications of AM textiles. Addressing this limitation required a second investigation of high-quality surface mesh generation to be undertaken.

Mesh generation: Re-meshing

The initial investigation of surface meshing revealed no satisfactory solution for the generation of a uniform and equidistant mapping mesh structure. A secondary line of investigation examined aspects of re-meshing that are normally utilised for the quality improvement of existing mesh structures for a range of applications, including; STL quality, FEA and rendering applications in polygon modelling systems. Re-meshing involves the manipulation of nodes and elements within an existing mesh structure based on a set of quality variables, typically element lengths and angle or aspect ratio. Normally these variables are defined within a maximum and minimum range and cannot be guaranteed globally throughout the resultant mesh structure, dependant on the underlying topology. Two excellent examples of Re-meshing software include Geomagics [Geomagics 2012] and Meshlab [Meshlab 2012], the latter being an open source shareware. Examples of the mesh quality delivered by both systems are demonstrated in Figure 15 based on the original STL mesh structure of a hand.

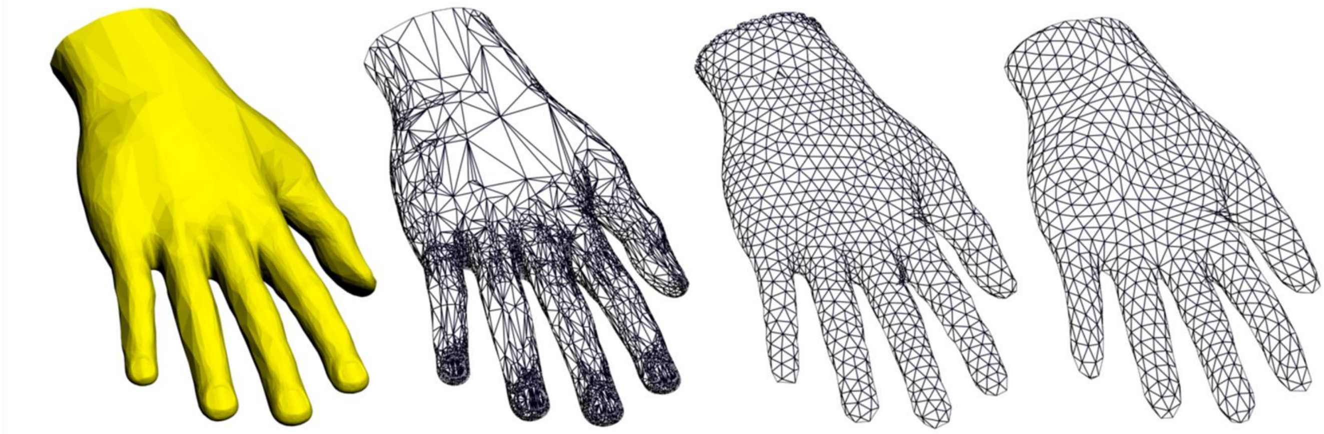

Figure 15: Re-meshing of hand STL data, middle right, Geomagics re-mesh and far right, Meshlab re-mesh

The documented re-meshed examples are high-quality in comparison to conventional surface meshing algorithms but do not attain the quality expectations required for AM textile generation, where uniformity (essential) with limited dimensional variability is required. To utilise such meshes, the mapping methodology required a scaling function to be included that allows the link geometry to be modified (scaled) based on the element lengths at each node location within the mesh structure. This was eventually included within the mapping software and the results of using the Meshlab re-mesh are demonstrated in Figure 16.

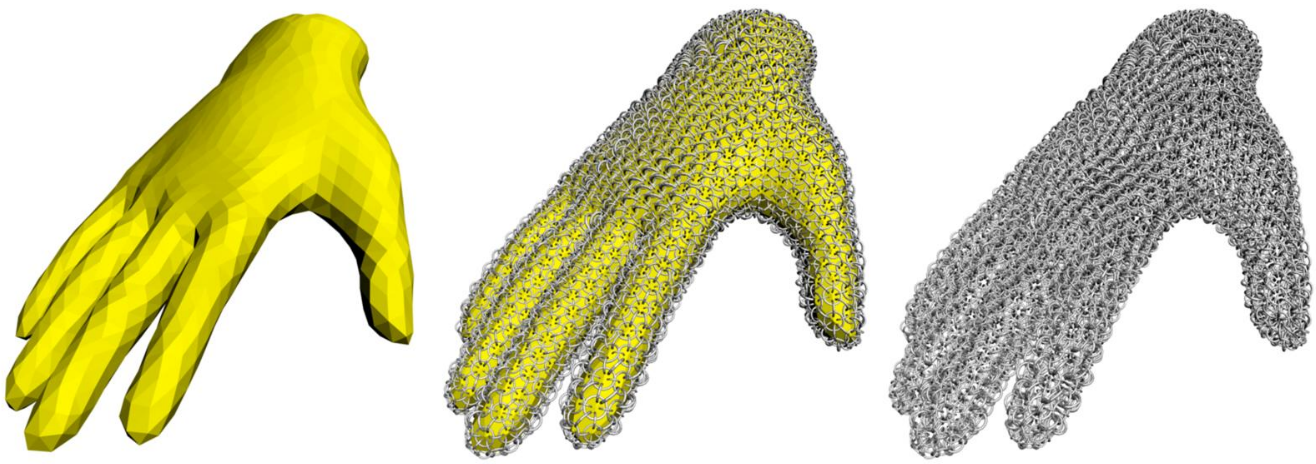

Figure 16: AM textile glove using Meshlab re-meshing process

The use of a scaling function within the mapping methodology and re-meshed surface meshes does allow the efficient generation of net-shaped and manifold AM textile artefacts. However, the irregularity within the mapping mesh structure (node to element ratio) reduces the range of possible link designs that can be utilised due to mesh structure not being completely uniform. The use of re-meshing also removes the ability to control the dimensions of the resultant links or their separation. These limitations can result in the data not being suitable for manufacture by AM techniques due to the specific separation tolerances requirements of built structures, typically 0.3mm for Laser Sintering. For some AM textile applications, the issues associated with using re-meshing can be tolerated, however, the aim of this research was the development of a method for the generation of uniform and dimensionally regular AM textile data.

Mesh generation: Mesh conforming

A further area of investigation was the notion of conforming a predefined mesh structure to a targeted surface topology. Mesh conforming has several qualities that make it an attractive alternative for the generation of AM textile data over re-meshing-based alternatives. The process of mesh conforming is demonstrated in Figure 15 and requires an initial planar mesh structure to be created with defined dimensions that is fitted (conformed) to a target topology based on specified variables, including mesh shear, element stretch and element compression [Autodesk 2012]. Control over these variables affects the defined planar mesh's ability to conform to the targeted topology but also affects the final distortion observed in the resultant mesh structure (element lengths). Through careful management of these variables a compromise can be generated, resulting in a surface mesh that approximates the targeted topology with a completely uniform structure and contains minimal dimensional variation.

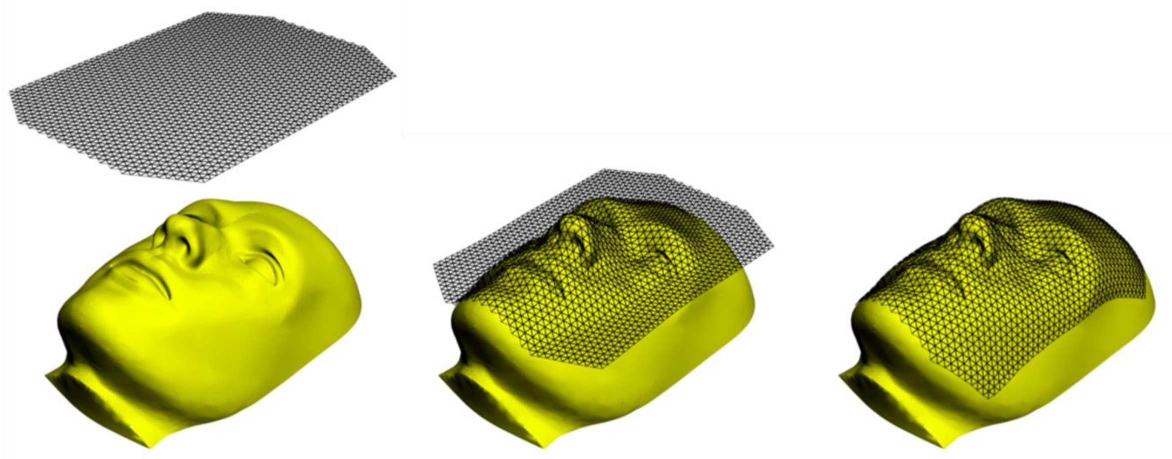

Figure 17: Mesh conforming process

The application of mesh conforming in combination with the new scaling function within the mapping software allows conformal AM textiles data to be efficiently generated, as demonstrated in Figure 18. This technique allows practical access to a range of complex topology far beyond the capabilities of the experimental meshing algorithm and produces higher-quality mesh structures (complete uniformity, typical element length +/- 0.5 units), and therefore higher quality AM textile data, then those generated by re-meshing techniques.

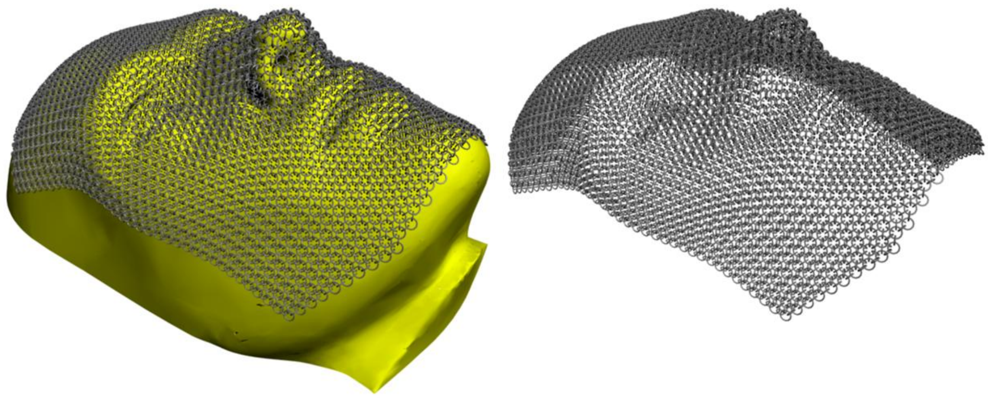

Figure 18: AM textile mask using mesh conforming process

Due to the uniformity of the generated mapping mesh, this technique also allows a greater range of AM textile link designs to be utilised (not shown). However, the use of mesh fitting for the generation of a mapping mesh does preclude the ability to generate net-shaped AM textile artefacts – this can only be achieved through re-meshing techniques as it is impossible to accurately conform a planar mesh to a manifold object without significant distortion at the boundaries of the fitted (conformed) mesh and the introduction of seams.

AM textile apparel modelling

A sub-aim of this research was the development of a methodology that would allow personalised (conformal) AM textile apparel data to be efficiently generated with suitable accuracy for manufacture by AM techniques. Using anthropometric data, or 3D body scanning data, the aim was the generation of a suitable mapping mesh that would allow accurate mapping of AM textile link structures for the production of a complete AM textile garment. Initially it was hoped that re-meshing techniques would provide the required mapping mesh but the discussed limitations prevent its application. The alternative to re-meshing was the application of mesh conforming but this introduces the requirement to have discrete seams between individual panels of conformal AM textiles. While not fully desirable, seams are a recognised and necessary component of conventional garment design/construction and therefore it is appropriate that they also become a necessary component of conformal AM textile garments design/construction. The methodology required by the application of mesh conforming for the generation of personalised AM textile apparel data can be summarised as follows:

1. Design individual AM textile link structure using conventional CAD software and export as STL data
2. Identify target surface topology for the final AM textile apparel (3D body scan data or anthropometric data)
3. Design panel layout of AM textile apparel based on target surface topology from stage two
4. Generate planar mapping meshes based on dimensional requirements of AM textile link structure from stage one and identified panels from stage three
5. Mesh conform the planar mapping meshes to all indentified panels from stage three
6. Extract conformed meshes from stage five as a single mapping mesh and trim any overlapping mesh elements
7. Import AM textile link structure STL data and final mapping mesh into mapping software

8. Identify all mapping locations (node and/or element midpoints) and calculate surface normal from mapping mesh
9. Copy original AM textile link structure and orientate to match required surface normal at the mapping location while remaining at the global origin
10. Scale AM textile link structure based on the elements lengths at mapping location
11. Translate orientated AM textile link structure to mapping location
12. Repeat stages nine, ten and eleven until every mapping location has been utilised
13. Export final AM textile apparel as STL data while omitting original AM textile link structure

Stages two, three and six of this methodology are illustrated in Figure 19.

Figure 19: Target topology (left), panel layout (middle) and complete mapping mesh (right)

The discussed methodology allows the generation of personalised AM textile garment data to be accurately generated, which is suitable for manufacture by AM techniques. However, the seams generated are a result of the interference between the individual panels of AM textiles and not a fully designed feature of the final AM textile garment as demonstrated in Figure 20, right. Further work is required to provide a dedicated seam generation technique.

Figure 20: Seams generated between individual panels of mapped AM textile link structures

The complete AM textile garment data generated using this methodology is demonstrated in Figure 21.

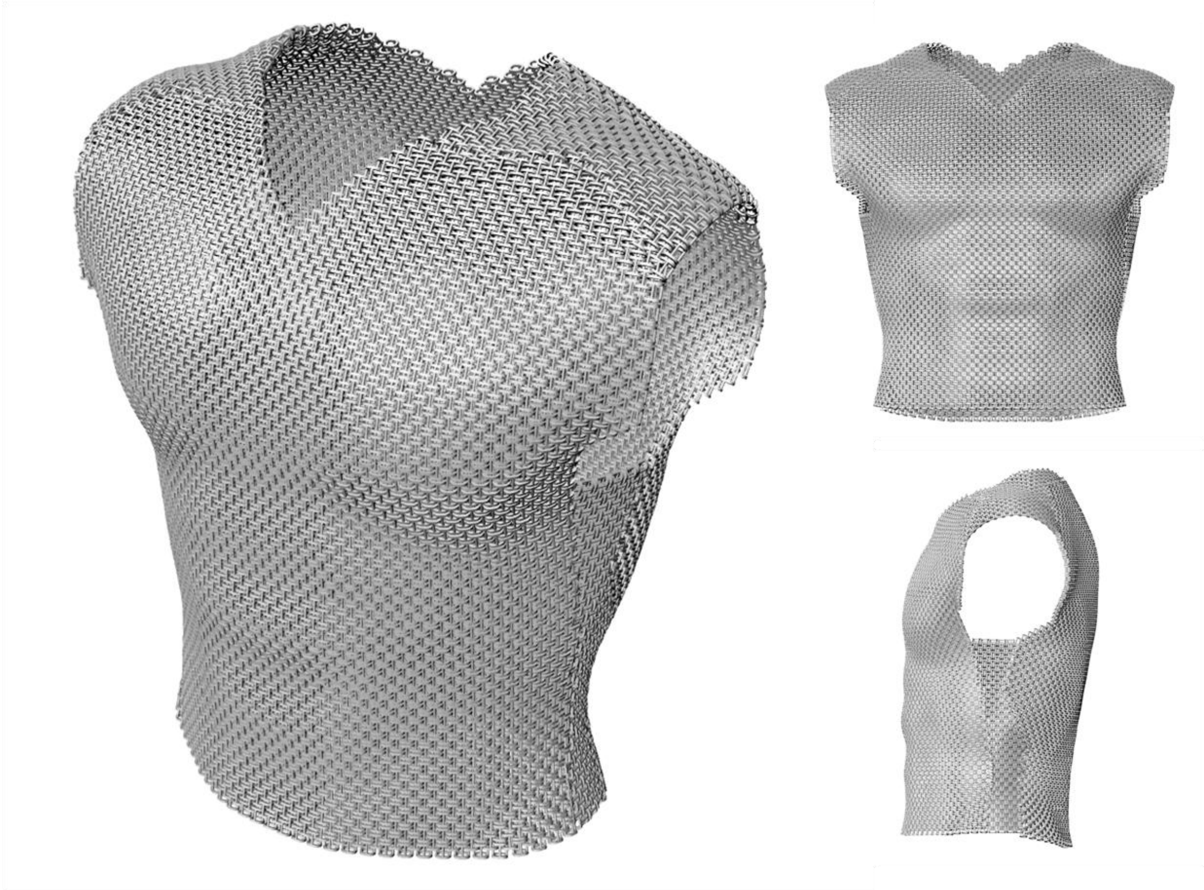

Figure 21: Complete AM textile garment using mesh conforming process

To validate the suitability of the complete AM textile garment data for manufacture by AM techniques (Figure 21), the STL data was inspected within Materialise's Magics software [Materialise 2012]. The complete AM garment was first modified so each individual link of the AM textile became a discrete part using the 'shells to parts' functionality of the software. Once complete, an interference check was performed between all parts to identify any interfering triangles of the STL data. The inspection revealed no interference within the structure except, as anticipated, for the seams. The interfering links at the seams where combined using the 'Boolean' functionality. The combined links at the seams introduce an element of solidity into the AM textile garment but still retain a level of movement.

Conclusion

The aim of this research was to investigate and develop an efficient means of generating conformal AM textile STL data suitable for manufacture. The research presented here demonstrates the issues surrounding the 3D modelling of conformal AM textiles using conventional 3D CAD systems and presents a methodology for the efficient generation of such complex 3D data based on the application of mapping meshes. The conclusions of the research can be summarised as follows:

- AM textiles provide a real opportunity for the design and manufacture of geometrically complex and potential high-performance textiles structures. However, practical access to an efficient means of generating conformal and net-shape 3D data restricts wider scale adoption and further investigation.

- Current CAD software solutions do not have the required capabilities to generate conformal AM textile data but do provide the modelling capabilities required for the design of complex individual link structures.
- Mapping complex geometries to a predefined surface mesh is a highly efficient means of positioning large numbers of individual elements without any user (manual) intervention.
- The presented methodologies provide the capability to map complex geometry described as STL data to an input surface mesh without any distortion of the mapped geometries or any user intervention.
- The presented methodology allows the original rotational orientation of the input geometry to be maintained throughout the mapping process.
- The limitations of the geometry mapping methodology for the generation of uniform and equidistant AM textile structures are directly related to the input mapping mesh. However, where uniformity and equidistance is not a requirement, the mapping methodology can be applied to generic surface mesh data from Re-meshing systems, FE pre-processors and polygon-based modellers for the generation of complex hierarchal structures of mapped geometries.
- Re-meshing techniques offer a viable solution for the generation of manifold mapping meshes but the quality of the data generated is not yet suitable for fully uniform and equidistant AM textiles. The inclusion of a scaling function within the mapping software does address some of the issues discussed but the lack of uniformity restricts the range of AM textile links designs that can be utilised.
- Mesh conforming provides completely uniform but dimensionally variable mapping meshes for an extensive range of complex topology. This technique provides high-quality mapping meshes and extends the capabilities of conformal AM textile generation. However, issues surrounding boundaries and seams require further investigation.
- Further limitations relate specifically to the datasets generated using the mapping methodology. STL format was chosen to simplify the 3D data import and export process of the mapped geometries, and while this succeeded in simplifying the process, STL data is considerably larger than alternative CAD-based formats, for example STEP or Parasolid. Therefore, the final dataset generated is a function of the imported data multiplied by the number of nodes and element midpoints utilised. For simple cases the data is entirely manageable, for larger surface meshes with thousands of nodes and element midpoints, combined with a complex mapping geometry, datasets can easily reach into the Gigabytes and therefore restricts the possibilities.

Further work

The presented methodology allows the efficient generation of conformal AM textile data. However, the suitability of the data generated is directly dependent on the quality of the input surface mesh. An experimental surface meshing algorithm was specifically developed for the task of AM textile data generation but further work is required to extend its capabilities to more complex surface topology. Alternatives for mapping mesh generation include re-meshing techniques and mesh conforming - further work addressing both of these techniques is required to extend the capabilities.

The methodology for generating AM textile apparel data is effective but further work is required to simplify the process and provide an alternative for seam generation. Further work is also required to explore the design and application of AM textile possibilities that this new methodology enables.

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