MULTIBLOCK GENERATION FOR HEXAHEDRAL MESHING OF IRREGULAR PROFILE

Submitted in accordance with the requirement of the University Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

SITI FATIMAH KHADIJAH BINTI MORTADZA
B051520013
950216-04-5208

FACULTY OF MANUFACTURING ENGINEERING

2019

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk : MULTIBLOCK GENERATION FOR HEXAHEDRAL MESHING OF IRREGULAR PROFILE

Sesi Pengajian: **2018/2019 Semester 2**

Saya **SITI FATIMAH KHADIJAH BINTI MORTADZA (950216-04-5208)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)

☑ TIDAK TERHAD

Disahkan oleh:

Alamat Tetap:	Cop Rasmi:
No.4, Jln Su 2,	
Tmn Sungai Udang,	
Sungai Udang 76300	
Melaka	
Tarikh: 9 January 2019	Tarikh: ________________________

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “Multiblock Generation for Hexahedral Meshing of Irregular Profile” is the results of my own research except as cited in the reference.

Signature : --
Author’s Name : SITI FATIMAH KHADIJAH BINTI MORTADZA
Date : 9 January 2019

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering the members of the supervisory committee are as follow:

……………………………………

(Masni Azian Binti Akiah)

ABSTRAK

Diskretisasi model reka bentuk bantuan komputer (CAD) ke dalam elemen yang lebih kecil biasanya dirujuk sebagai proses jejaring. Proses jejaring adalah strategi kritikal untuk pemodelan dan simulasi unsur terhingga (FE). Teknik jejaring yang baik adalah dengan membahagikan model asas kepada beberapa elemen ideal bagi membolehkan pengiraan berkomputer dilaksanakan dari mana-mana aplikasi FE. Salah satu cara untuk menilai kualiti mesh ialah dengan menggunakan penentu nilai Jacobian. Elemen jejaring dengan Jacobian bernilai negatif merujuk pada elemen yang sangat herot, sementara angka Jacobian yang bernilai positif menunjukkan elemen jejaring yang sempurna dan dapat digunakan untuk melaksanakan simulasi berkomputer. Unsur berbentuk hexahedron dan tetrahedron adalah antara bentuk yang selalunya dipilih untuk pembahagian objek. Tidak seperti komponen hexahedron, komponen tetrahedron memerlukan lebih banyak elemen untuk membentuk model geometri dengan lengkap. Jumlah elemen jejaring yang lebih tinggi menghasilkan lebih banyak masa pengiraan dan kos simulasi yang lebih tinggi. Walau bagaimanapun, penggunaan elemen hexahedron bagi geometri dengan profil yang kompleks sangat mencabar kerana lokasi kelengkungan yang tinggi biasanya akan mengakibatkan kehilangan ketetapan jaringan, komponen yang tidak berfungsi dan kualiti mesh yang rendah. Untuk permukaan struktur yang lebih kompleks, lebih banyak masa diperlukan untuk menghasilkan model dengan elemen hexahedron sepenuhnya. Oleh kerana profil permukaan yang semakin kompleks, teknik meshing yang sedia ada adalah tidak sesuai. Oleh itu, matlamat penyelidikan ini adalah untuk mewujudkan satu algoritma yang membantu proses penjaringan model CAD kepada element hexahedron terutamanya untuk geometri dengan profil permukaan yang kompleks dengan menggunakan pendekatan blok binaan. Jejaring dengan elemen hexahedron akan dibina dengan merujuk kepada bentuk blok binaan dan kualiti elemen akan dinilai berdasarkan penentu nilai Jacobian. Hasil daripada kajian yang telah dijalankan dapatan menunjukan bilangan elemen terdistorsi yang dihasilkan telah dapat direndahkan mengunakan teknik yang telah dicadangkan. Kaedah yang telah digunakan berkait rapat dengan penggunaan mapping blok teknik yang telah banyak digunakan didalam kajian- kajian yang lepas. Hasil yang diperoleh dinilai berdasarkan nilai Jacobian yang diperolehi selepas proses diskretisasi. Nilai Jacobian akan menentukan sama ada kualiti permukaan mesh memenuhi keperluan untuk proses simulasi.

ABSTRACT

Discretization of the computer aided design (CAD) model into smaller elements are commonly referred as the meshing process. The meshing process is a critical strategy for finite element (FE) modelling and simulation. An appropriate meshing technique includes apportioning the basic model into perfect element that enable estimation from any FE application. One of the method to evaluate the mesh quality is using the determinant of Jacobian value. Mesh element with negative Jacobian number alludes to a very distorted element, while positive Jacobian number demonstrates perfect mesh element and can be executed for finite element simulation. The hexahedral and tetrahedral element is among the component that are usually chosen for object meshing. Unlike hexahedral component, tetrahedral component requires more number of element to completely characterize the model's geometry. Higher element numbers resulted to more computational time and higher simulation cost. However, appointment of hexahedral elements to geometry with irregular profile is very challenging since the high curvature locale will usually lead to loss of mesh constancy, misshaped component and poor mesh quality. For higher structural complexity, more time is required to create a fully-hexahedral mesh model. As the structural complexity of the profile increases, the current meshing technique may be insufficient. Therefore, the aim of this research is to create an algorithm that can assist the fully-hexahedral meshing process for geometry with irregular surface profile by utilizing the building block approach. A fully-hexahedral mesh will be built up with reference to the building block which is built in reference to the CAD model with irregular profile, and the mesh quality will be assessed based on the determinant of the Jacobian value. The results of the study have shown that the number of distorted element produced has been lowered using the proposed technique. The results obtained were evaluated based on the Jacobian value obtained after discretization process. Jacobian value will determine whether the quality of a mesh surface meets the requirements for the simulation process. The methods used are closely related to the use of the mapping block technique that has been widely used in previous studies.

DEDICATION

I am grateful to the divine presence for giving me the strength to complete my study of this thesis. I would also like to thank both parents (Mortadza Bin Ab Karim and Sakinah Binti Yusoff) and my family members who gave much encouragement and blessing throughout my study. Also, not to forget my stepmother (Zuraini Bibi Binti Muhammad Yusoff) for giving infinite moral support. I love all to the end of life.

ACKNOWLEDGEMENT

In the name of my beloved God, I would like to extend my thanks to my research supervisor Mrs. Masni Azian Binti Akiah who has provided many guidance and encouragement and sharing of knowledge in solving my thesis. In appreciation to Muhammad Faiz Bin A Razak for giving much help and moral support throughout the course of this thesis. Thank you for never stopped believing in myself when I face difficulties that caused me to give up in pursuing these studies. Acknowledgments to my supervisory family for the sake of allowing me to have a project meeting session at their home and outside working hours. Finally, I want to express my gratitude for my friends who always give me encouragement and help and always share their knowledge in managing the project phase.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	-	3 Dimention
CAD	-	Computer Aided Design
FE	-	Finite Element
GUI	-	Graphic User Interface
Id	-	Identification
OK	-	Okay
PSM	-	Projek Sarjana Muda
STL	-	Standard Tessellation Language
VTK	-	Visualization Toolkit

CHAPTER 1
INTRODUCTION

1.1 Research Background

Before any mechanical simulation can be performed on a structural geometry, a computer aided design (CAD) model have to be established, followed by discretization of the CAD model into smaller elements to allow the structure to be computationally analysed under specific loading and boundary conditions (Figure 1.1). Discretization of the CAD model into smaller elements are commonly referred as the meshing process. A good meshing technique involves partitioning the structural model into ideal elements that enable calculation from any finite element (FE) application. One of the method to measure the quality of the meshing element is based on the element's volume ratio. The meshing phase become significantly important in ensuring an ideal volume ratio for 3D element can be achieved. The volume ratio can be computed using the determinant of the Jacobian value which compares the volume of the meshed element to the natural coordinate of an ideal element. Mesh element with negative Jacobian value refers to highly distorted elements, while positive Jacobian value indicates ideal mesh elements. In order to ensure simulation can be performed from any FE tools, the meshed elements must have a positive Jacobian value. Meshing elements with negative Jacobian value should be avoided at all cost as it could prevent the FE application from running the simulation process (Grosland, Bafna, et al., 2009).

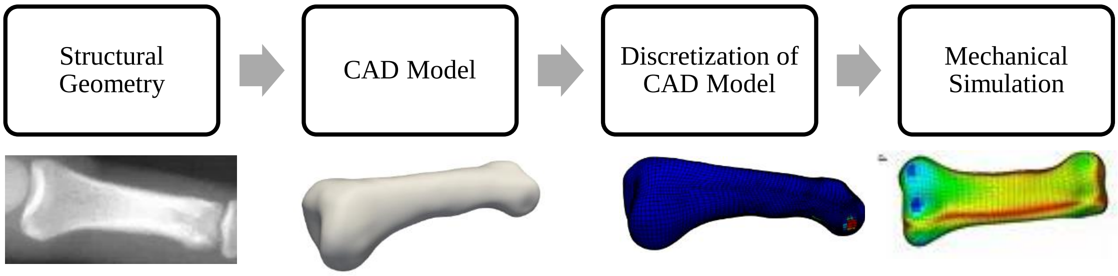


Figure 1.1 The process of computational simulation

There are many types of mesh element. The hexahedral and tetrahedral element are among the element that are commonly selected for object meshing (Figure 1.2). The hexahedral element has a cubical shape while the tetrahedral element have a triangular shape. Compared to hexahedral element, tetrahedral element requires more number of elements to fully define the object's geometry. Higher element numbers would usually result to longer computational time, and hence, higher simulation cost.

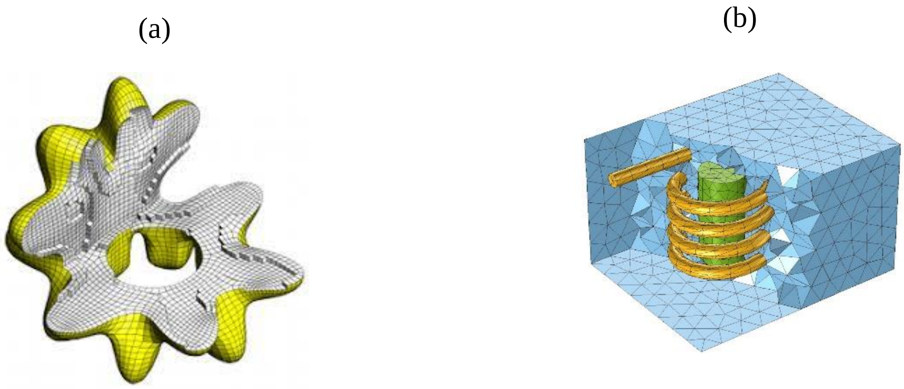


Figure 1.2 (a) Example of mesh with a hexahedral element mesh and (b) tetrahedral element

Generating an ideal hexahedral mesh element for structural features particularly with irregular surface profile have been a challenge in FE studies. The differences between geometry with regular and irregular profiles are illustrated in Figure 1.3. Biological parts in particular (example human bones) usually have highly irregular shape. Discretizing irregular surface profiles into fully-hexahedral elements have been a challenge among computational researchers as there are higher risk for the discretized elements to show a lower mesh quality with highly distorted element (Yang, 2018a). Hence, simulation engineers dealing with irregular surface profile usually choose tetrahedral elements to execute their simulation.

(a) (b)

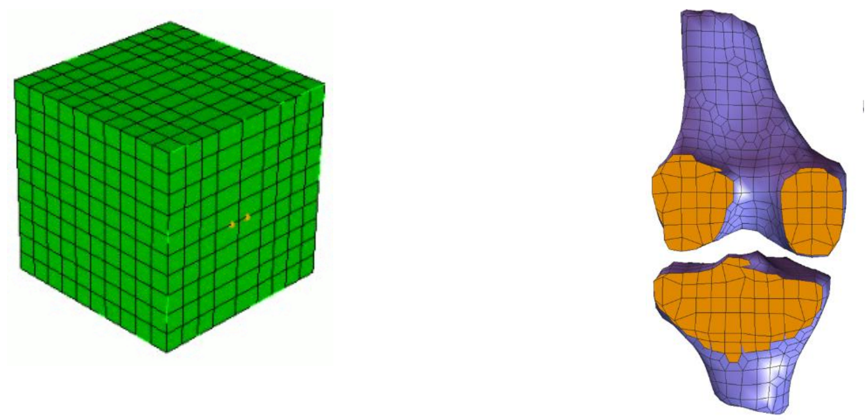


Figure 1.3 Different types of geometrical features. (a) Regular surface profile, and (b) Irregular surface profile.

IA-FEMesh is an open-source software, which was initially developed to assist meshing of anatomical parts into hexahedral elements. The software employs generation of building block which surround the CAD model (Figure 1.5). Seeds of hexahedral elements are then translated from the edges of the building block towards the nearest point on the surface of the CAD model to generate a fully-hexahedral meshing (Figure 1.4). Currently, the building block can only be altered in the IA-FEMesh environment using their graphic user interface (GUI). However, as the geometrical complexity increases, alteration of the building block in the IA-FEMesh environment becomes increasingly difficult, especially when orienting and altering the nodal points of the building block in 3D space. As a result, the mesh quality will vary and highly depends on the user's skill to establish an ideal building block. Therefore, it is the interest of this study to develop an algorithm than can be executed to develop the building block for different irregular profiles to ensure consistent meshing results. Furthermore, this study intends to explore the possibility to establish fully-hexahedral mesh elements especially for geometry with irregular profiles as it is expected to reduce computational time, increases FE computational stability and reduce simulation cost.

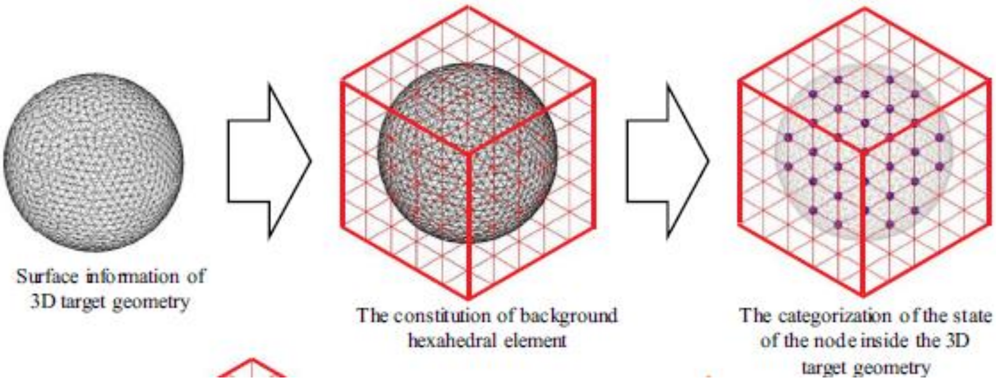


Figure 1.4 Meshing Process of a hexahedral element based from seed value.

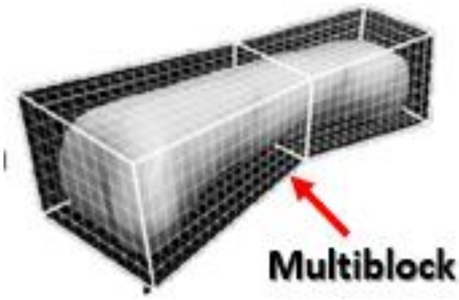


Figure 1.5 Building Block In IA-FEMesh Environment

1.2 Problem Statement

(a) Producing the mesh element for a regular shape geometry is easier compared to the geometry with irregular shape as the geometry can be discretized accurately. When meshing irregular profile into fully-hexahedral elements, there is an increased tendency for the meshing quality to become poor based on the high number of elements with negative Jacobian value. Elements with negative Jacobian value are extensively distorted from the ideal hexahedral shape. Most FE application (eg. ANSYS, Simulia, and Providance) will generate error and terminate any simulation when elements with negative Jacobian value is detected (Yang, 2018b).

(b) Currently, the effort needed to generate fully hexahedral mesh with positive Jacobian value especially for geometry with irregular profiles is very time-consuming (Yang, 2018a). As the structural complexity increases, the present meshing technique become insufficient (Shivanna et al., 2010). The irregular profile becomes the main focus in this study because of the high curvature region that may lead to loss of mesh fidelity, distorted element and poor mesh quality (Shivanna et al., 2010).

(c) Certain profile features like corner and ridges require extra attention during meshing so that the geometry can be reproduced accurately. In medical-engineering field, the meshing process which accurately reflect subject or patient-specific specimens are much more challenging compared to mechanical models (Mao et al., 2013). Sometimes, the effort in developing a fully-hexahedral mesh element of an irregular profile become even more complicated compared to the simulation process itself.

1.3 Objective

The aim of this research is to develop a systematic algorithm that can expedite the fully-hexahedral meshing process for geometry with irregular surface profile using the building block approach. It is expected that the algorithm can reduce the number of distorted hexahedral mesh element and can be applied to various geometries with irregular profiles.

The specific objectives are as follows:

a) To determine the hexahedral mesh element quality of geometry with irregular profile by using manually constructed building block for single and multiple building block approach.

b) To develop multiple building block algorithm that can reduce the number of distorted hexahedral mesh elements.

1.4 Scope

(a) Geometry of irregular profile that will be considered in this study is (Figure 1.6):

i. Sphere.

ii. Index proximal bone.

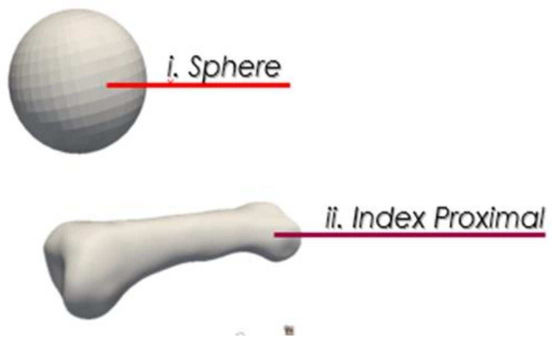
iii. Distal Phalanges

iv. Middle Phalanges

v. Proximal Phalanges

vi. Metacarpals

(a)



(b)

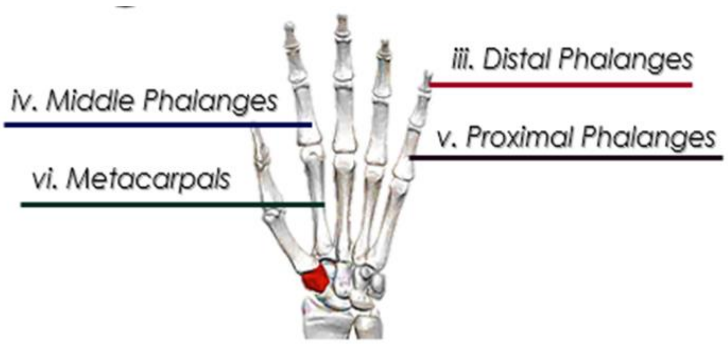


Figure 1.6 Position and illustration of the model used in the mesh process (a) Model used in PSM1 (b) Model Used in PSM 2

(b) Maximum number of building block that will be considered in this study is only up to 8-blocks.

(c) Mesh element quality is determined based on the determinant of Jacobian value.

(d) Meshing discretization will be performed using the IA-FEMesh software.

(e) Development of multiple building block algorithm will be performed using Python programming language.

1.5 Rational of Research

The rational of this research as follows:

(a) The mesh generation is an important procedure in any FE modelling and simulation. However, higher structural complexity require more time to generate the mesh (Shivanna et al., 2010). Therefore, we intend to gain knowledge regarding the meshing technique that can improve the meshing quality of the selected profile.

(b) As the structural complexity of the profile increase, the present multiblock meshing may be inadequate for the meshing process (Shivanna et al., 2010). Without proper meshing technique and poor meshing quality, the FE simulation cannot be performed at all. FE simulation is important to evaluate structural behaviour including measurement of stresses and strains of complex geometry given the loading condition and material properties. Good FE model will ensure more accurate estimation of the mechanics of the CAD model.

(c) Application of the FE method in biomedical engineering is a growing research interest. However, due to high geometric complexity of biological component, the FE computation analysis become challenging as it could cause a high amount of time and manual effort to create an adequate and valid FE model (Grosland et al., 2009).

1.6 Research Methodology

The research consists of two main phases (Figure 1.7). Initially, the geometric profile of an irregular profile is selected and the STL data is established. In the first phase, which is accomplished during PSM 1, the preliminary building block is generated based on the STL data using the IA-FEMesh GUI. In the IA-FEMesh environment, the building block is developed without node alteration and with manual node alteration. The manual node alteration of the building block depends on the user definition in the IA-FEMesh GUI. Next, fully-hexahedral mesh is generated in reference to the building block, and the mesh quality is evaluated based on the determinant of the Jacobian value. In the second phase, which is accomplished during PSM 2, the development of the algorithm of multiple building block will be established. Accordingly, fully-hexahedral mesh will be established, and the mesh quality will be determined based on the determinant of the Jacobian value. Variation to the mesh quality value will be evaluated and research will be concluded.

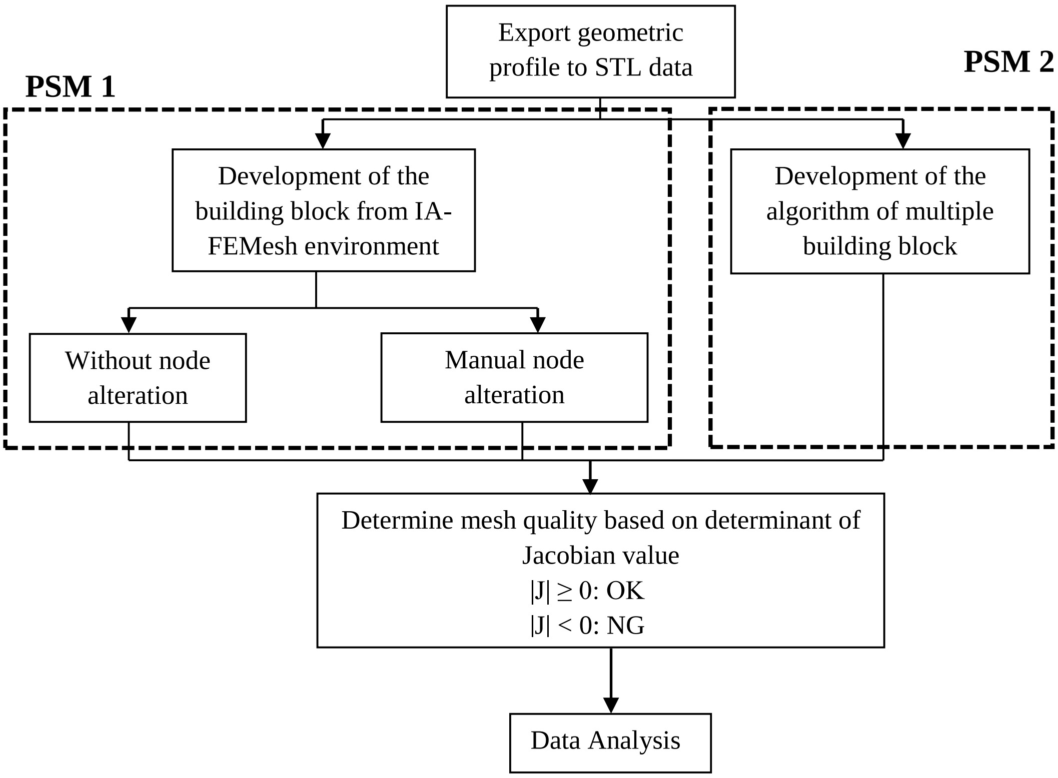


Figure 1.7 Flow Chart for the Final Year Project