Report, Kinetic project

Dorian Geraldes Pereira, Axel Demuth

March 2024

Contents

1 Introduction

Our project is part of a larger initiative aimed at processing IFC files representing buildings to create 3D models for energy simulations with high-performance calculations.

1.1 Project Objective

Within this project scope, the primary goal is to implement an efficient and accurate conversion process for Industry Foundation Classes (IFC) files representing buildings or cities into meshes compatible with the Kinetic algorithm. Subsequently, the Kinetic algorithm will be applied to these meshes to produce watertight models, facilitating the execution of finite element calculations.

The specific steps to be undertaken are as follows:

1. **Reading Process or Mesh Conversion :** From the IFC files we will have a conversion in the stl or msh format,we will need to change the reading process to be able to read mesh from those format if possible,if we cant then we will convert the STL or MSH meshes into one of the formats accepted by the Kinetic algorithm, such as .ply, .xyz, .las, .off.
2. **Application of the Kinetic Algorithm:** Applicate the Kinetic algorithm on the the converted meshes to produce meshes optimized for finite element calculations.
3. **Recovery of Material Labels:** Ensure the preservation of information regarding materials present in the initial IFC-format mesh and correctly associate them with elements of the converted mesh.
4. **Utilization on City Modeling:** Extend the application of the Kinetic algorithm to entire city models.

1.2 Project Challenges

Currently, the project faces several technical challenges:

1. **Generating point cloud from stl file:** To use the kientic algorithm we need a point cloud format with normal on each point, currently the result we get from the transformation arent satisfactory we need to find a solution to improve this conversion
2. **Parameter Optimization:** Identify and adjust appropriate parameters to avoid segmentation faults and achieve satisfactory results when applying the Kinetic algorithm.

By overcoming these challenges, the project aims to provide a comprehensive and efficient solution for analyzing urban structures using the Kinetic algorithm to facilitate finite element calculations.

2 Tools

2.1 CGAL

CGAL is a comprehensive package for geometry algorithms, providing various data structures and algorithms for working on polygons, surfaces, mesh generation, and more. It offers a wide range of functionalities for geometric processing and analysis in various fields such as computer graphics, computational geometry, and geometric modeling.

2.2 IFC Format

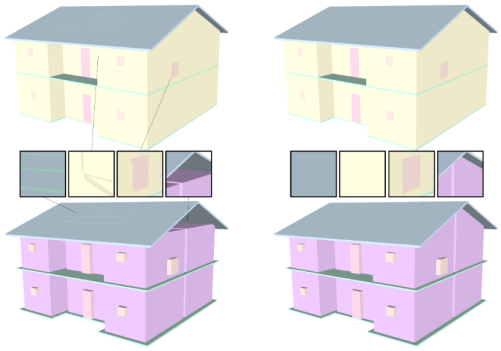
The initiative was created by buildingSMART (BIM), with the goal of supporting portability between software in the construction sector. IFC is a file format designed to replace a fragmented information system with a standardized one. This enables every actor in the sector to utilize IFC-compatible software to open files and model their contents without wasting time and computational resources on convertion between different formats.

The IFC format is a volume-based 3D representation , The file is very similar to object-oriented code, with numerous classes associated with various needs such as construction sites, tools, and materials. However, a challenge we face is the difficulty in interpreting IFC objects for use in Kinetic programs. While there are several software solutions available to convert IFC to the desired format, we often lose significant amounts of information in the process.

As a result, we need to focus on refining the objects received from the converting process to ensure that Kinetic algorithm can effectively read the files.

2.3 Kinetic

Kinetic algorithm(KSR) is a package from CGAL that allows working on meshes with some holes in them. When applied to the mesh, the Kinetic algorithm will 'extend' some surfaces to fill the mesh and make it watertight. Here's what the algorithm is capable of:



3 Implementation

We are using the most complete example of the cgal kinetic algorithm as base for our main.
To use the algorithm we currently advice to imput a file in those format: ply, off, xyz, las. Our main is now able to read STL and MSH format but for now by transorming the point of the format in an xyz file, but for now the result of this transformation is still bad because of the density of point given by the transformation compared to the density needed by the algorithm. In this main we can change every parameters of the algorithm but if the parameters dont respect the critera we described in the Test of parameters section (3.5) the algorithm can end up in segmentation fault. The result of the algorithm will be in an off format in "result" folder.
We can present example of the command to execute the program:
'./build/default/bin/kinetic -data data/flame.ply -dist 0.3 -minp 50 -regangle 5 '
'./build/default/bin/kinetic -data data/ACJasmin_Mesh.ply -dist 0.3 -minp 300 '

3.1 File Format

In this project we use different files Format as:

- XYZ : An XYZ file contains point cloud data with each point's coordinates in 3D space.
- PLY : A PLY file stores 3D model data including vertices, faces, and optional attributes like color and normals.
- STL : An STL file represents the surface geometry of a 3D object using triangular facets.

3.2 STL Reading and Use

In the CGAL library, we have methods to read various file formats such as PLY, OFF, and XYZ, including STL files. When we use the 'read stl' function, we obtain the following output:

- A list of all points used in the mesh.
- A list of vertices with all points used in every polygon.

Thus, we have access to a point cloud and a list of polygons. The KSR algorithm only needs a point cloud to work. We proceed by calculating the normals associated with all points, writing all the points and normals into an .xyz file, and then reading the .xyz file with our main program to apply the KSR algorithm. However, one issue with STL files is the low number of points they provide, which leads to suboptimal performance of the algorithm and potential

errors. Therefore, we need to find a way to densify our point cloud. To execute KSR on our files, we tried different options:

- Using free and open source software such as CloudCompare.
- Using CGAL methods to densify our point cloud, such as the CGAL Poisson surface reconstruction.
- Using Meshlab sampling functions as Monte Carlo sample or Poisson dist Sample

3.3 Kinetic algorithm

We can obtain a comprehensive understanding of how it works in general from the report by INRIA [5].

- It uses geometric primitives to create planes due to their relevance in human-made environments.
- There are multiple methods for plan fitting in a 3D model, such as Neural Network architectures or Energy-based Models. The algorithm employs the latter.
- To evaluate the quality of a primitive configuration x with an energy U of the format
  $U(x) = w_f U_f(x) + w_s U_s(x) + w_c U_c(x)$
  where all U functions pertain to fidelity, simplicity, and completeness, and all w are positive and weight.
- It then utilizes geometric operations such as merging, splitting, transfer, insertion, and exclusion on different planes and closed primitives.

Here, we present pseudocode detailing how the exploration of the set of primitives works:

Algorithm 1 Pseudo-code of the exploration mechanism

```
Initialize the primitive configuration x
repeat
    Initialize the priority queue Q
    while top operation i of Q decreases energy U do
        Update x by operation i
        Update Q
    end while
    Update x by the global transfer operator
until no update modifies x any more
```

The priority queue represents the set of primitives to which we apply geometric applications.

To use the algorithm, we employ one from CGAL. Given a set of parameters and a file containing a point cloud along with the associated normals to the points, the algorithm is applied. We were fortunate to have a meeting with Florent Lafarge, one of the creators of the algorithm, who explained to us which parameters are crucial for analysis and how each one can significantly influence the results. Two parameters stand out as particularly important:

- 'dist' indicates the distance between two points required to consider them for plane construction.
- 'pmin' represents the number of points used to construct a plane.

3.4 Data

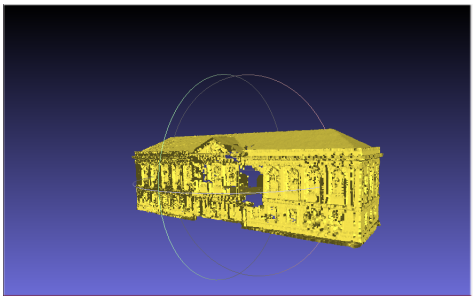
We obtained our different meshes from different sources with the name of the files:

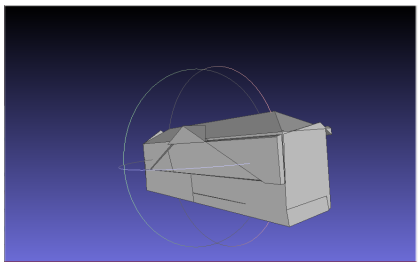
- from the KSR example package from INRIA : flame.ply
- from the package `data_point_3` from CGAL : building.ply
- from Vincent Chabannes : 3zones.stl , ACJasmin.stl

3.5 Test of the parameters

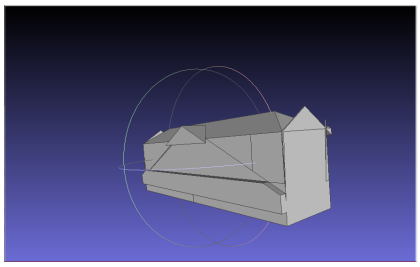
In order to understand how these parameters affect the outcome, we will examine the same point cloud while varying the value of 'pmin' first and then varying 'dist.' The algorithm produces .off files as output, which can be visualized using software such as MeshLab.

The original point cloud represents this building :

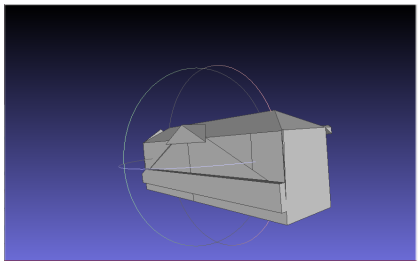




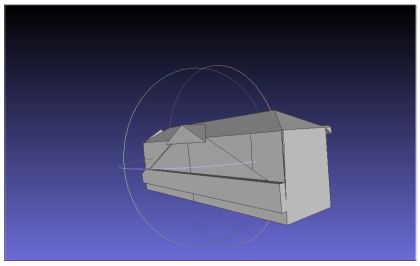
(a) dist1_pmin220



(b) dist1_pmin250



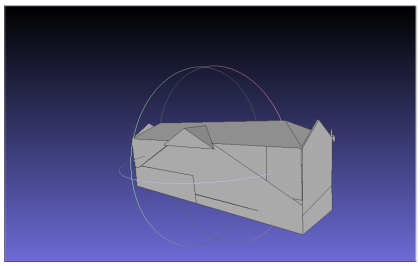
(c) dist1_pmin280



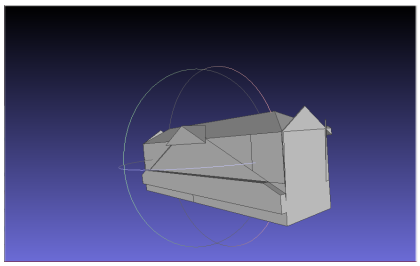
(d) dist1_pmin300

Figure 1: Variation of p_min on building.ply

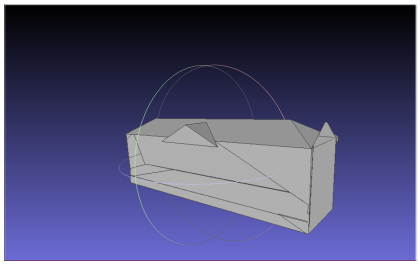
First, it's important to understand that setting 'pmin' too low can lead to errors. Subsequently,if 'pmin' is too small, we may not capture enough structural detail, whereas setting 'pmin' too high may cause planes to overlap, resulting in loss of information



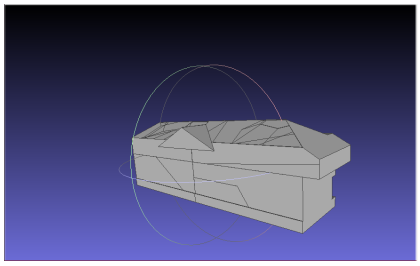
(a) dist15_pmin250



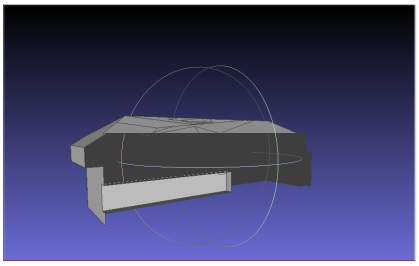
(b) dist1_pmin250



(c) dist0.3_pmin250



(d) dist0.01_pmin250



(e) back_dist0.01_pmin250

Figure 2: Variation of dist on building.ply

When considering the 'dist' parameter, if it is set too high, we risk losing significant structural details. In the opposite, if the distance is too small, surfaces may be divided into too many planes, potentially resulting in an incomplete coverage of the entire mesh, as observed at the rear of the building with a 'dist' of 0.001.

One of the challenges in studying this algorithm is determining the appropriate 'qmin' and 'dist' to achieve the desired number of space partitions. Setting it too high may enhance precision but extend execution time, and in some cases, incorrect values can lead to program crashes.

This algorithm could be a crucial tool in our project, particularly when dealing with massive meshes for large buildings, hospitals, etc. When creating large meshes, issues can arise, and errors within the mesh can be detrimental during simulations,potentially leading to false results. This algorithm allows us to rectify such mesh problems.

One limitation of the algorithm is its input requirement, as it currently only works with scatter plots. Consequently, we are unable to utilize the IFC format, resulting in the loss of valuable information regarding the types of structures present. To address this limitation, we plan to implement a process involving the conversion of IFC to scatter plot with associated data, followed by conversion to formats such as .plt, .ply, .xyz, which are supported by Kinetic CGAL, ultimately resulting in a mesh with associated data.

3.6 CloudCompare

We used CloudCompare to create a densified point cloud with an stl file as basis. This software can also calculate normals of each point, we used it sometimes to see the differences with cgal and meshlab because the normals of the point are very important to get the best result possible

3.7 CGAL Methods

CGAL offers multiple ways to generate point clouds in theory. For example:

- $CGAL :: Spatial\_sort\_traits\_adapter\_3$ and $CGAL :: natural\_neighbor\_coordinates\_3()$, interpolation methods like least squares or spatial interpolation.
- $CGAL :: Delaunay\_triangulation\_3$ for triangulation of a mesh.
- $CGAL :: point\_generators\_3 :: regular\_grid\_points()$ for generation on a grid.

If we succeed in generating a sufficiently large point cloud with one of these functions, we could try to write it in OFF, XYZ, or PLY files to read them and attempt to assemble the mesh to achieve the desired result. However, even if we manage to build our programs using one of these functions, we do not always get the results we want. For example, to use the neighbor coordinates, we first need to perform Delaunay triangulation. However, one problem with our STL file is that it's a non-oriented mesh, so CGAL cannot calculate the Delaunay triangulation. Another problem is meshes with stairs, which implicate many points close to each other, causing errors in the generation process.

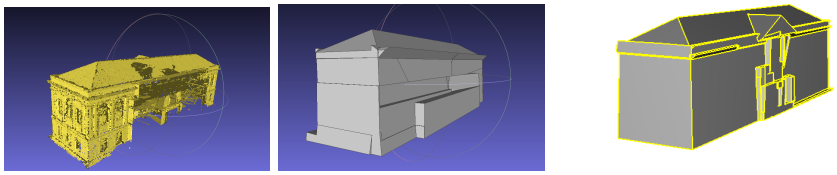
4 Analysis of results

4.1 first results

Analysis of the meshes reveals significant differences between those produced by the CGAL algorithm and those generated by the INRIA algorithm. The mesh obtained with CGAL demonstrates satisfactory watertightness but is characterized by noticeable roughness. Conversely, the mesh generated by the INRIA algorithm is remarkably smoother, offering a more uniform surface.

For better visual understanding, three images are provided below:

- Initial point cloud
- Result of the mesh with the CGAL algorithm
- Result of the mesh with the INRIA algorithm

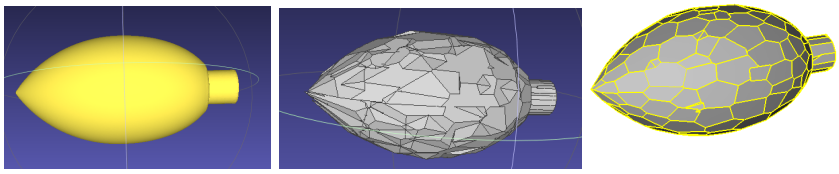


point cloud,
file: building.ply

cgal result,
data: building.ply,
parameters: -dist 0.4
-minp 100 -regangle0 5

inria result,
data: building.ply

Figure 3: Visualization of results with building.ply



point cloud,
file: flame.ply

cgal result,
data: flame.ply

inria result,
data: flame.ply

Figure 4: Visualization of results with flame.ply

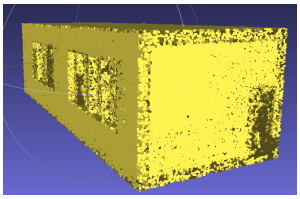
4.2 Final Result

For the final analysis we worked on 2 of the example provided by Vincent Chabannes:

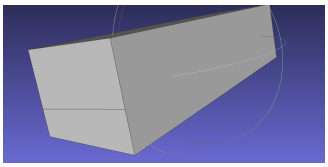
3zones ACJasmin ACJasmin_inside

Figure 5: Visualization of STL files that serves as basis for the following example

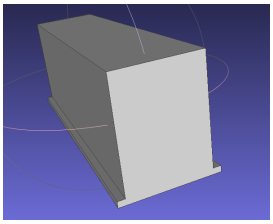
For the first example, 3zones, we used CloudCompare to create the PLY point cloud file for the CGAL algorithm, and we calculated the necessary normals in Meshlab, which gave us the best results. However, the resulting watertight mesh lost all the details from the STL file, such as the windows and doors, which have disappeared. We can also see the importance of the normals calculation for the algorithm.



point cloud



result normal by MeshLab, data: 3zones_normal5.ply, parameters: -dist 0.2 -minp 500

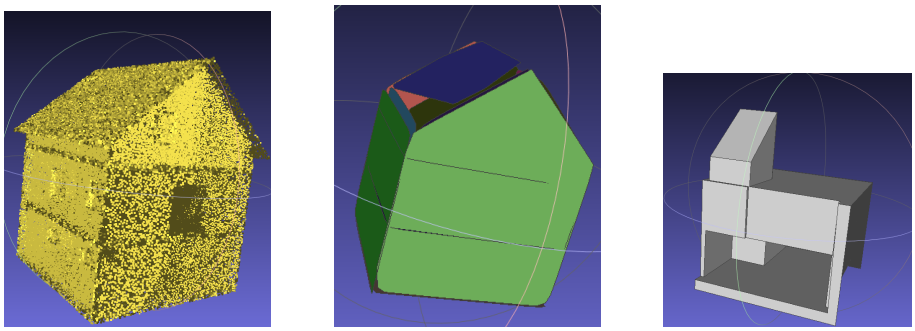


result normal by cgal, data: 3zones_normal_apres.ply, parameters: -dist 0.2 -minp 500

Figure 6: result with 3zones example

For the second example, ACJasmin we used the same protocol as the first example but for this example we decided to remove the ground around the house because it created a lots of problems, the result we got were a lot more

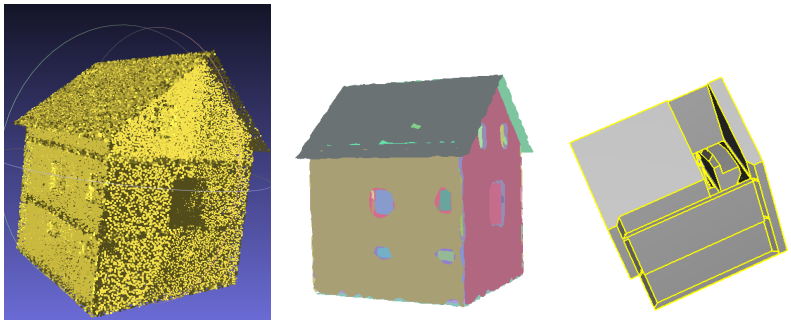
disapointing than the first example. The mesh we got is open and we lost nearly every detail like the first example just a bit of the stairs still remained This is the result we got from the cgal version:



point cloud | primitives | result, parameters: -dist 0.3 -minp 300

Figure 7: result of ACJasmin with cgal, data: ACJasmin_Mesh.ply

After the cgal version we tried the IRNIA version the result was still disapointing but better:



point cloud | primitives | result

Figure 8: result of ACJasmin with cgal, data: ACJasmin_Mesh.ply

As we can see in those images the results we have from the algorithm isnt really satisfactory we need to find a solution to improve the quality of the outcome.

5 Roadmap

At this point those are the main Issues that we will need to work on:

- Create better data to use the algorithm (mesh orientation and normal calculations)
- If possible, be able to retrieve the labels on the mesh generated by the Kinetic algorithm.
- Quality check of the obtained mesh from the kinetic algorithm (same volume as the first mesh)
- Apply physical theories to the base mesh and the output mesh to analyze the differences between them.
- Investigate the feasibility of applying the algorithm on a larger scale, such as a city or a large building, instead of a basic one.

For the V1 we modified and completed some issues:

- The Issues Create watertight mesh with kinetic we completed what we wanted to do with this issue but now we want to go further so we modified it to create watertight mesh from files coming to IFC format for the V2
- The issue Convert IFC to PLY format was also changed to change the reading process or convert MSH and STL to supported cgal format for the V2
- The issue setup programming environment for CGAL with github action and submodul,the creation of the main program,the study of the kinetic program were completed

6 Conclusion

The kinetic algorithm serves the purpose of upgrading meshes and making them watertight, even if some details are lost in the process. However, there are still many limitations regarding its application, and significant preprocessing of the mesh may be required before executing the algorithm. Even after converting the STL mesh into a point cloud for the kinetic algorithm, the results are not satisfactory.

We can explore different ways to improve our results. Future work should focus on orienting the mesh from the STL file and generating a better point cloud. By ensuring the mesh is correctly oriented, we can effectively apply Delaunay triangulation or other CGAL methods without encountering errors to generate a denser and more accurate point cloud will enhance the performance of the KSR algorithm and lead to better outcomes in our applications.

7 Reference

References

[1] Cloudcompare - 3d point cloud and mesh processing software.

[2] Ktirio - construction et immobilier.

[3] Jean-Philippe Bauchet and Florent Lafarge. Kinetic Shape Reconstruction. *ACM Transactions on Graphics*, 2020.

[4] The CGAL Project. *CGAL User and Reference Manual*. CGAL Editorial Board, 5.6.1 edition, 2024.

[5] Mulin Yu and Florent Lafarge. Finding Good Configurations of Planar Primitives in Unorganized Point Clouds. In *CVPR 2022 - IEEE Conference on Computer Vision and Pattern Recognition*, La Nouvelle-Orléans, United States, June 2022.

[6] Mulin Yu, Florent Lafarge, Sven Oesau, and Bruno Hilaire. Repairing geometric errors in 3D urban models with kinetic data structures. *ISPRS Journal of Photogrammetry and Remote Sensing*, 192, October 2022.