UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

BIM Based Machine Learning Framework for Healthcare Facilities

Document:
Report

Autor:
Bjørn Harald Høgmo

Director /Co-director:
Nuria Forcada Matheu/ Hamidreza Alavi

Degree:
Master in Technology and Engineering Management

Examination session:
Autumn, 2022 - 2023

MASTER FINAL THESIS

Abstract

English:

Traditional design approach for construction projects spans over several steps, from design phase, collaboration phase, construct phase and operation and management phase. Each phase consists of its own methodology and intermediate steps or intervals. Preliminary stages of a project involve data collection and specification of the requirements, among several points, and within a healthcare facility the specifications are given by stakeholders and the users of the facility. To create good projects, the quality of the specifications relies heavily on the experience of the representants, while the interpretation of the specifications and creation of design rely on the experience of the designers. Such a manual creation of data collection, specifications and design are prone to human errors, only assessing a few alternatives and what worked earlier design approach.

Contrary, machine learning (ML) and Building information modelling (BIM) software could assess thousands of alternatives and modified according to different optimization parameters. Therefore, the creation of a preliminary design model based on actual clinic data and their electronic health records (EHR), optimization of layout based on EHR and patients' movement, which again could be connected to a automate creation of BIM model. Each of the separate areas, creating a machine learning on one side and atomate create BIM on the other hand has a potential benefit to generate savings, reduce length of preliminary phase and reduce labor hours.

This thesis suggests a methodology for combining ML algorithms for optimization in hospital layout problems (HLP) design with the automate creation of 3D BIM model. Such a methodology is shown possible, and the report concludes such an approach is feasible. The methodology steps use of machine learning algorithm to create optimized layout solutions with coordinates in the 2-dimensional (2D) plane, where a visual programming Automa create a 3D BIM model for use in the preliminary phase.

Spanish:

El enfoque de diseño tradicional para proyectos de construcción abarca varios pasos, desde la fase de diseño, la fase de colaboración, la fase de construcción y la fase de operación y gestión. Cada fase consta de su propia metodología y pasos intermedios o intervalos. Las etapas preliminares de un proyecto implican la recopilación de datos y la especificación de los requisitos, entre varios puntos, y dentro de un centro de salud, las especificaciones las dan las partes interesadas y los usuarios del centro. Para crear buenos proyectos, la calidad de las especificaciones depende en gran medida de la experiencia de los representantes, mientras que la interpretación de las especificaciones y la creación del diseño dependen de la experiencia de los diseñadores. Tal creación manual de recopilación de datos, especificaciones y diseño es propensa a errores humanos, ya que solo evalúa algunas alternativas y lo que funcionó con el enfoque de diseño anterior.

Por el contrario, el software de aprendizaje automático (ML) y modelado de información de construcción (BIM) podría evaluar miles de alternativas y modificarse de acuerdo con diferentes parámetros de optimización. Por lo tanto, la creación de un modelo de diseño preliminar basado en datos clínicos reales y sus registros de salud electrónicos (EHR), la optimización del diseño basado en EHR y el movimiento de los pacientes, que nuevamente podría conectarse a una creación automática del modelo BIM. Cada una de las áreas separadas, la creación de un aprendizaje automático por un lado y la creación automática de BIM por otro lado, tiene un beneficio potencial para generar ahorros, reducir la duración de la fase preliminar y reducir las horas de trabajo.

Esta tesis sugiere una metodología para combinar algoritmos ML para la optimización en el diseño de problemas de diseño de hospitales (HLP) con la creación automática de modelos BIM 3D. Tal metodología se muestra posible, y el informe concluye que tal enfoque es factible. Los pasos de la metodología utilizan el algoritmo de aprendizaje automático para crear soluciones de diseño optimizadas con coordenadas en el plano bidimensional (2D), donde una programación visual Automa crea un modelo BIM 3D para usar en la fase preliminar.

Table of contents

List of tables

List of figures

List of equations

List of abbreviations / Glossary

2-dimensional (2D) 1
3-Dimensional (3D) 1
building information modelling (BIM) 1
comma separated values (CSV) 29
critical pathway (CP) 3
discrete-event simulation (DES) 3
Electronic Health Records (EHR) 1
electronic healthcare records (EHR) 4
generative adversarial network (GAN) 3
genetic algorithm (GA) 4
healthcare systematic layout planning (HSLP) 3
hospital layout planning (HLP) 3
Layout planning (LP) 3
metaheuristic (MH) 3
operating departments (ODs) 3
Particle Swarm Optimization (PSO) 3
Probabilistic Determining Finite Automa with Particle Swarm Optimization (PDFA-PSO) 4
significant critical pathways (CPs) 3
simulation-optimisation (SO) 3
systematic layout planning (SLP) 4
systematic literature review (SLR) 5

1 Introduction

Effective design of buildings and hospitals strongly relies on successful collaboration among all participants, and complexity of modern architecture increases the challenges and enhance the problem of collaboration among architects, engineers, stakeholders, and users (Staff and patients/customers/workers). In conventional design, all stages are treated separately, and conceptual and preliminary designs are highly leading to constrains and limitations in the following phases. Establishing an early or preliminary design for a healthcare facility also rely heavily on user involvement from healthcare professionals, stakeholders and healthcare designers to establish the clinic or healthcare facilities needs based on existing experiences, existing layout solutions layouts, experienced patients flow and patients and staff feedback. Such a user involvement is mainly based on the experience on already establish personnel and patients.

Traditional design methods for healthcare facilities could be described in 4 steps, data collection and building information modelling (BIM) model design/creation, establish workflow for design based on BIM, construct, and handover. Epically the data collection and creation of preliminary design are a time consuming and labor-intensive phase, as the data collection is based on input from the stakeholder and users, while the design in based on model creation by architects. This method relies heavily on the experience of the involved parts.

Possible new methods for creating an optimized solution for layout based on Electronic Health Records (EHR) data and algorithms is on the rise and has in some cases already been implemented in actual hospital clinics. This optimized solution is implemented in the early stages of design. Another part of the design in the early preliminary stages is to create a 3-Dimensional (3D) model for the ability to visualize and discuss the suggested solution with the stakeholders and users.

This master thesis will develop a method for automatically creating this 3D BIM model from the bases of outputs from algorithmic optimization of a design, to save time consuming and labor demanding creation of BIM

1.1 Aim

The aim for this master thesis is to integrate Machine Learning into the BIM model to provide a framework for healthcare facilities optimizing patient tracking.

1.2 Scope

To use machine learning algorithm to crate optimized 2-dimensional (2D) solutions, which gives an output of the optimized room location with x and y coordinates.

This output is used as an input into a visual programming creating the BIM model automatically.

1.3 Requirements

The requirements for this project are:

- Use of BIM software Revit
- Use of Visual programming language in Dynamo
- Use of Python programming

- Use of Pycharm editor, editor for Python

2 Background – State of Art - Missing

2.1 Layout optimization in health care

Layout planning (LP) aims at ordering organizational units or resources that consume space within a building or facility such that the available area is used optimally, and total space are minimized. These resources might include a cabinet, a desk, a work centre, an entire office, a room, or even a department. LP is performed any time there is creation of a new building or facility, or an expansion or a space reduction within existing building or facility.

Hospital Layout Planning (HLP) is the equal to LP but within a hospital or healthcare facility. Relevant research papers are reviewed to identify the current practice and gaps in the literature involving HLP. Chraibi, et al. (2016) researched the implementing of intelligent decision systems to achieve benefits through optimization of health care processes and improving the efficiency performance of staff at operating theatre at Roanne hospital in France. They seek to find the layout of facilities in a hospital department in compliance with international health care accreditation standards, and to meet the internal constraints on the organizational layout, while the main objective is to minimize the total traveling costs among facilities and to maximize the desirable adjacency among pairs of facilities while meeting the above-mentioned requirements, and therefore take benefit from potential savings and the recent technological advancement. They use information as activities in a department, number of trips made, set of activities in a department, entity types: doctor, patient, medical staff or non-medical staff, cost factor, and etc. This information was given and not listed in their study. (Chraibi, et al., 2016) uses a mathematical formulation to obtain optimal layouts for small-sized instances as well as proposing a Particle Swarm Optimization (PSO) to obtain approximate and near optimal layouts for large-sized instances.

Arnolds & Gartner (2018) investigate the value of data-driven critical pathway (CP) mining for strategic healthcare management. They encounter the problem in three stages: In the first stage, an algorithm to learn significant critical pathways (CPs) from large transactional data. In that stage, address the problem to determine CP probabilities including those which have not been observed in the data but are likely to occur in the future. In the second stage, they introduce a mathematical model that allows the performance of hospital layout planning decisions based on the CPs and their probabilities as learned in the first stage. In the third stage, (Arnolds & Gartner, 2018) approaches the learning on a real-world setting using different performance measures.

Vahdat, et al. (2019) aim to improve the patient experience and present new mathematical methods for supporting the layout design of healthcare clinics with a focus on improving quality and patient satisfaction by minimizing patient walking distances during their visits. Focus on walking distances is particularly critical for patients with mobility restrictions and senior patients. According to their study they reference (Rui & Okeyode, 2015) which states that patients with mobility restrictions and senior patients accounted for nearly 20% of outpatient visits in 2011. Their study examines the design of a pediatric orthopedic outpatient clinic and expands upon the current literature of outpatient clinic layout design, proposing a data-driven simulation-optimization (SO) approach via utilization of mathematical modelling to solve the problem. By integrating (PSO), a metaheuristic (MH) algorithm, and a discrete-event simulation (DES) model, this framework provides a set of promising solutions for a large-scale complex outpatient clinic layout design problem.

A study performed by Zhao, et al. (2021) on two intelligent design processes based on healthcare systematic layout planning (HSLP) and generative adversarial network (GAN). Their goal was to solve the generation problem of the plane functional layout of the operating departments (ODs) of general hospitals. The first design method that is more like a mathematical model with traditional optimization algorithm concerns the following two steps: developing the HSLP model based on the conventional systematic layout planning (SLP) theory, identifying the relationship and flows amongst various departments/units, and arriving at the preliminary plane layout design; establishing mathematical model to optimize the building layout by using the genetic algorithm (GA) to obtain the optimized scheme. The specific process of the second intelligent design based on more than 100 sets of collected OD drawings includes: labelling the corresponding functional layouts of each OD plan; building image-to-image translation with conditional adversarial network (pix2pix) for training OD plane layouts, which is one of the most representative GAN models. Finally, the functions and features of the results generated by the two methods are analyzed and compared from an architectural and algorithmic perspective. Comparison of the two design methods shows that the HSLP and GAN models can autonomously generate new OD plane functional layouts. The HSLP layouts have clear functional area adjacencies and optimization goals, but the layouts are relatively rigid and not specific enough. The GAN outputs are the most innovative layouts with strong applicability, but the dataset has strict constraints.

The research of (Halawa, et al., 2021) studies the designing of an healthcare facility layout with pod structures using a framework of algorithms to create an optimized layout bases on electronic healthcare records (EHR) data where records for patient identification numbers, encounter dates, provider names, provider types, visited departments, appointments lengths, rooming times and checkout times is provided. The EHR data allows tracking of the sequence by patients. (Halawa, et al., 2021) proposes a three-phase framework, where the first phase implemented a process mining algorithm that modifies the Probabilistic Determining Finite Automa with Particle Swarm Optimization (PDFA-PSO) algorithm to predict the flow of patients, while the second phase uses a simulation modelling, whereas the final and 3rd phase imposes a Unequal area facility layout problem. The final result is then a prediction of an optimized layout for the facility.

The review of relevant works shows an emerging field focused on the integration of algorithms and simulation to improve the data quality and accuracy for healthcare layout optimization models. The main output from these studies is in form of optimized layouts based on optimization with regards to the flow of patients. However, the studied works do not show an implementation of the result into a real-life project phase, but rather supply a solution possible to use in preliminary phases, and further manually handled by the designers. The new standard for all phases, including early preliminary stages of a project is to establish and use a building information modelling (BIM) model. The studied works do not create or establish the transformation from programming to BIM: The use of BIM enables the visualization of the project from the first stages of the model, and by integrating a optimization phase with Automa creation of a BIM model enables the direct transfer from optimization to preliminary project stages.

2.2 Building information modelling

BIM is a digital representation of physical and functional characteristics of elements or spaces which contains information and characteristics about the objects stored in computer files. In other words, a digital BIM object could be said to be a digital twin of a physical object including its values as for example u-value, concrete properties, sound resistance with more. These data could be exchanged between supported software and technologies, and BIM are used to plan, design and manage constructions and infrastructure, and it’s a technology which fit well to 3D visualize projects.

But BIM is so much more than a technology, it’s a sophisticated design and construction process that enables architects and designers to create buildings and infrastructure projects with realistic 3D visualization.

This is now a 'standard' in the construction industry and used the following way in building and construction design projects. Step 1, modelling, from early stages designers use BIM as a modelling tool with a BIM software. The second step, workflow and exchange, the BIM model with all the information about the project are stored in a shared location, that clients, architects, engineers, contractors collaborate. The workflow and the ability of the model includes analyses like light, cost, construction process, material choices and more. Step 3, the construction process, contractors construct the building by revising the BIM model and extract all relevant information. Designers could make adjustments if needed, and the contractor then have the changes right there. Step 4, handover, the model could also be used in a handover between contractor and landlord, and further directly to facility management (FM). It could be said that BIM is useful from projects ideas to the maintenance over its lifespan.

An emerging area for BIM is the use in FM, which is an organizational workflow combining the elements of people, place and process in the building operational stage. A problem for BIM in FM is that the quality and updates between the FM and BIM are the separated management of the BIM in the FM process which leads to a large amount of data missing when there are inevitable changes during the building operational phase. (Wen, et al., 2020) propose a solution to exchange the information provided by the BIM with the parameters of particular FM systems while (Hamidavi, et al., 2020) suggest that such a "model can be extended by employing some technologies such as Artificial Intelligence (AI) and Internet of Things (IOT), which would coalesce together to create a fully integrated and automated solution" to collect and enhance the occupants' comfort in a building. As BIM methodology are becoming very relevant for all stages of the project's lifecycle, more data are managed across the different workflow stages, including FM.

As a BIM model introduces a digital model with a high level of 'data-richness' it introduces "a new digital way of working that enables a collaborative process to capture and manage the whole lifecycle of an asset at any stage of it is lifecycle for different purposes ranging from representation and planning to estimation, simulation, and management of a project" according to (Zabin, et al., 2022). Equal to trending use of BIM in FM, a general trend of machine learning (ML) is developed in all aspects of engineering and engineering software. ML is a set of mathematical techniques that make it possible to develop algorithms that learn not from you telling them exactly to do, but by developing logical responses based on data. The use of ML offers a unique possibility, here mentioned some of them; (Howe, 2017) describes the use of generative design software which is capable of producing an endless number of customized layouts plans by initial parameters and to satisfy specify criteria associated with the decried outcomes, (buildingSMART, 2022) give uses as assigning geometry in one click and discover and copy elements, compositions, materials, story heights, window and stair parameters and so on and automatically apply it to a new model, model a advanced connection once and then apply it to similar connection by one click, create a 3D BIM model from a scanned point cloud of a building, while (Zabin, et al., 2022) performed a systematic literature review (SLR) and discovered that for designers ML has been implemented to automate building design with data from different projects, automated rule checking for local regulations, green building design and optimizing energy performance, in construction phase planning and visualizing construction activities, creating shop drawings, improved risk management.

Automatization has a number of possible usage areas, and a massively improvement potential on the design process compared to traditional approaches.

2.3 Summary

Studying the emerging trends of using EHR data and algorithms to optimize healthcare facilities could give early design phases an alternative and different approach to establish a preliminary solution for designers and healthcare stakeholders to discuss. This approach has the potential to give massive savings compared to a traditional design approach as the traditional design approach methods is a time consuming, labor intensive and requires several complex input stages which involves stakeholder and users to generate an early proposed solution. The use of BIM in all design phases are the ‘new standard’, and all major construction and infrastructure projects uses BIM in all stages and as a collaboration tool between engineering disciplines, and when changes in a design phase the BIM model are also passed on. The emerging use of BIM includes it in the usage in the FM in the lifespan of the building establish BIM as the ‘way of creating construction projects and maintaining buildings and infrastructure projects.

In the context of ML applications to BIM, the applications are still in an early stage of development. As discussed above the potential for implementing the methodology from algorithms to BIM in the healthcare sector to create a ‘new way’ of preliminary design phase combining EHR data, layout optimization and Automa creation of a BIM model could result in reduced time consumption and reduce labor hour. It could represent an upside for the sector.

3 Methodology

As discussed above, the potential upside to create a methodology for a system connecting machine learning algorithms to Automa creation of a BIM model could improve effectiveness in an early-stage design process to overcome a time consuming, labor intensive and timely approach. This master thesis proposes such a methodology to challenge the traditional design process for a hospital- department, area, clinics or similar.

The study discusses a two-step methodology to achieve such a model. To be specific, the first step is to identify performance parameters and indexes, and to create input frame for a algorithm and perform simulations to generate optimized 2D layouts. Then it is to generate a script with visual programming to interpretated the output from the prior optimization process to generate input to BIM software and to create a 3D BIM visualization. The software performing these steps are as follows, PyCharm editor for Python and as BIM software Revit. Dynamo, a visual programming extension for Autodesk Revit, and Python programming language.

3.1 Algorithm

This thesis proposes and uses a PSO algorithm. PSO is a population-based search algorithm and is initialized with a population of random solutions, called particles. These particles fly through space and are dynamically updated and adjusted according to their previous behavior and position. Each particle has best position, and the best positioned particle has a global best position, and as it a learning algorithm, the particles have a tendency to move towards the best position resulting in a situation where all particles end up at the global best position.

A general PSO algorithm was used and modified to accommodate the input for a proposed hospital clinic and to output a 2D layout optimized with the global best position for each room with its x and y coordinate system. (Bendjoudi, 2018). The modified code could be seen in annex a and annex b

EHR are not available for this study. Therefore, the evaluation starts from constructing input parameter system screened out by a HLP literature review and then the parameters were indexed for input to a PSO algorithm

3.2 Building information modelling integration

To establish an optimized 3D BIM visualized in the BIM software Revit, a script is established to interpret the output from the PSO algorithm. The script is created in Dynamo, a module which consist within Revit for visual programming. Dynamo is used for creating Automa operations in Revit or to function as a base for parametric design.

These data could be exchanged between supported software and technologies, and BIM are used to plan, design and manage constructions and infrastructure.

3.3 Assumptions

This master thesis report has taken the following assumptions for the creation of PSO input:

- All the rooms are fixed sizes of a random size, inspired from (Vahdat, et al., 2019)
- Room types are set, and inspired from (Vahdat, et al., 2019)
- All the rooms have fixed door position of a randomly choose position
- The corridors are non-present – but incorporated in unused/free area and area between rooms

4 Particle Swarm Optimization for hospital layout

4.1 Particle Swarm Optimization

The theory of PSO originates from the social behavior of flying birds and their methods of information exchange. It is an evolutionary optimization calculation technique based on the birds concept of swarm intelligence, and introducing one bird as a particle, and hence the name particle swarm optimization. The original intention of the particle swarm optimization concept was the graphically simulate the graceful and unpredictable behavioral movements of a bird flock, to avail the patterns that govern the ability of birds to fly synchronously, and to rapidly change direction by re-grouping in a other and optimal formation. And from this initial objective, the concept evolved into a efficient and jet simple optimization algorithm. In PSO, individual particles, , are "flown" through hyperdimensional search space. (Uzila, u.d.) describes it "Changes to the position of particles within the search space are based on the social-psychological tendency of individuals to emulate the success of other individuals. The changes to a particle within the swarm are therefore influenced by the experience, or knowledge, of its neighbors." The behavior of an individual particle is affected by that of other particles within the swarm. The consequence of modelling this social behavior is that the search process is conducted such that particles stochastically return toward previously successful regions in the search space. In other words explained by (Ito & Suzuki, 2022) "The next state of each individual is generated based on the optimal solution in its search history ("personal best"; xpbest), the optimal solution in the combined search history of all individuals in the swarm ("global best"; xgbest), and the current velocity vector."

Modelling this social behavior is that the search process is performed such that particles stochastically return toward former successful regions in the search space. (Shi & Eberhart, 1998) describe their PSO pseudo code as follows:

"

```
For each particle
Initialize particle

END

Do
    For each particle
        Calculate fitness value
        If the fitness value is better than the best fitness value (pBest) in history set current
        value as the new pBest

    End
    Choose the particle with the best fitness value of all the particles as the gBest

    For each particle
        Calculate particle velocity according equation
v[ ] = v[ ] + w*c1 * rand( ) * (pbest[ ] - present[ ]) + w * c2 * rand( ) * (gbest[ ] - present[ ] )
```

Update particle position according equation

present[ ] = persent[ ] + v[ ]

End

where pbest –the best solution that has been achieved by the particle so far and gbest - the best value obtained so far by any particle in the population. It adopts the following internal parameters:

w – an interia coefficient (w= 0.3)

c1, c2 – learning factors (c1 and c2 = 2)

rand( ) - uniformly distributed random variables within range [0, 1]

"

4.2 Input parameters for PSO

In this study the following was created with inspiration from other reports, and the first step is to create input data, which is done with inspiration in the above-mentioned studies and figures from their studies.

Raw data in this report provides rooms, room sizes and the correlation between the rooms in form of patients walking paths.

The following has been created:

Table 1, Room list and room sizes

Unit/Room	Unit count	Width [cm]	Length [cm]
Check-in	1	500	700
Waiting area	1	1000	900
X-ray room	1	1000	800
Cast room	1	2000	900
Exam room	1	900	840
Physican work area	1	1500	850

Table 2, Patient flow overall probability

Description	Flow variant	Probability
Check in - Waiting - Xray - Cast	CWXC	31,5 %
Check in - Waiting - Xray - Exam	CWXE	25,0 %
Check in - Waiting - Exam - Physician	CWEP	13,0 %
Check in - Waiting - Cast - Exam	CWCE	13,5 %
Check in - Waiting - Xray - Physician	CWXP	12,0 %
Check in - Xray	CX	5,0 %
SUM		**100,0 %**

Table 3, Probability matrix of movements of patients

Check in	Waiting	Xray	Cast	Exam	Physician	Total probability
1	1	0,9	0,35	0	0	0,315
1	1	0,5	0	0,5	0	0,250
1	1	0	0	0,26	0,5	0,130
1	1	0	0,9	0,15	0	0,135
1	1	0,24	0	0	0,5	0,120
1	0	0,05	0	0	0	0,050
					SUM	**1,000**

This research proposes created data to be used in the first step instead of actual clinic data and transform it into a form that can be analyzed. In Table 1 you can see the room list including sizes. In the research by (Halawa, et al., 2021), data is used as follows, and herby quoted "EHR raw data provides records for patient identification numbers, encounter dates, provider names, provider types, visited departments, appointment lengths, rooming times, and checkout times. This data allows tracking of the sequence by patients. Preprocessing of the data results in a dataset consisting of the patient pathways" and then "Algorithm 1 extracts the significant patient pathways from preprocessed EHR data using PDFA."

In this study we have defined the matrix shown in Table 3 in the following way, a patient path can go to the Check-in – Waiting – X-ray and Cast. To calculate the probability of a patient following the pathway, the product of transitional probabilities and probability of a final state should be calculated by following the path from start through the whole path; hence, here represented as 10/10 * 10/10 * 9/10 * 3.5/10 = 3,15/10, and therefore as the total probability on 31,5 %.

While this study uses the input as set number of rooms, and a set probability, this data could easily be as a dynamic input of variable number of rooms and scenarios of movements within a clinic or similar.

4.3 PSO simulations

4.3.1 Initial layout generation

The PSO algorithm needs initial solutions to initiate solution space exploration. The algorithm generating a random initial layout solution. According to (Chraibi, et al., 2016) "Much research works proved that the quality of initial solution has an influence on the quality of the final solution, and it tends to achieve early convergence to the best solution." However, this research it is presented a totally random layout suggestion. Figure 1, Figure 2 and Figure 3 shows examples of the randomly arrangement of rooms in the available space.

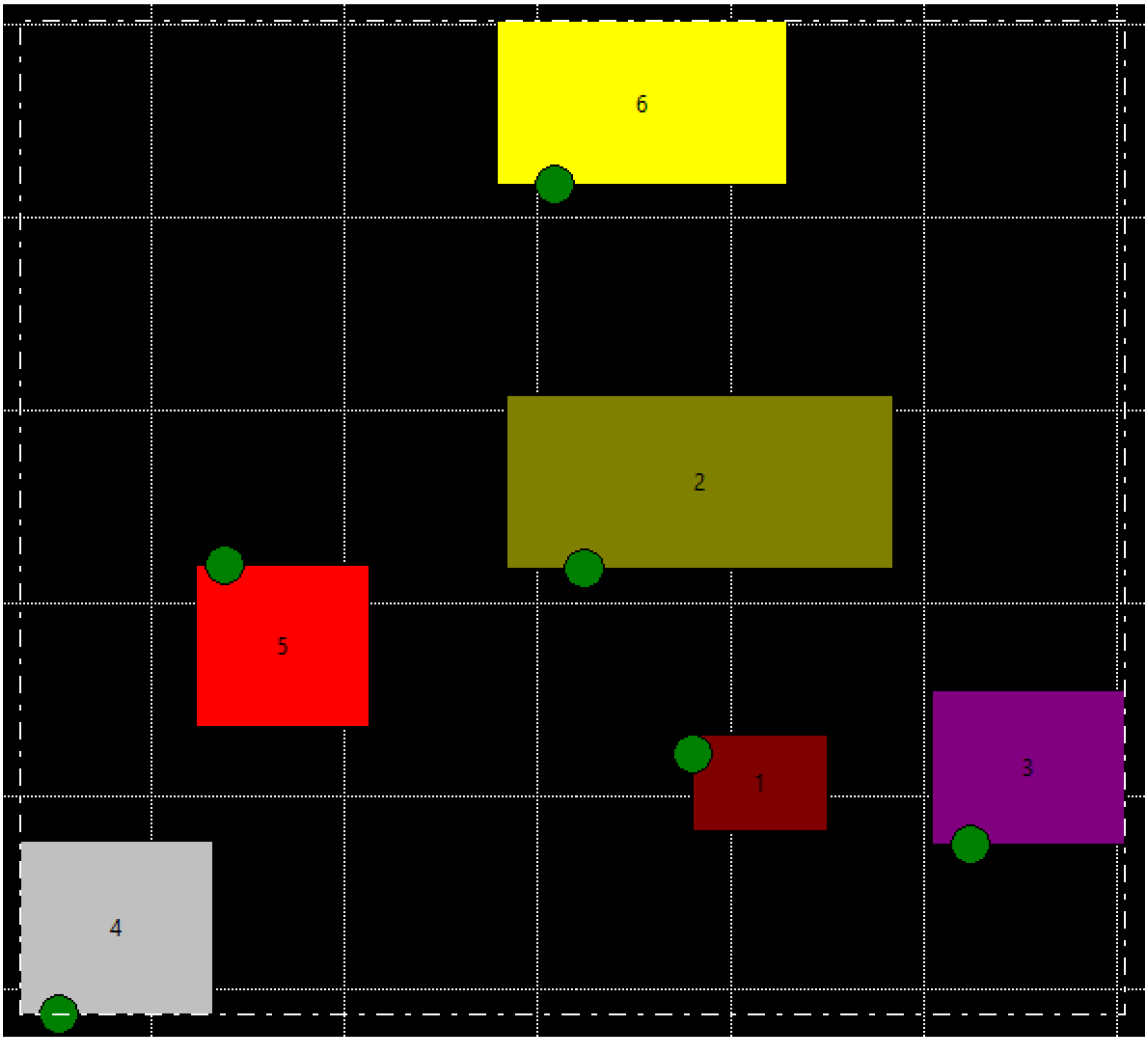

Figure 1, Example of random generated initial layout (Before optimization)_1

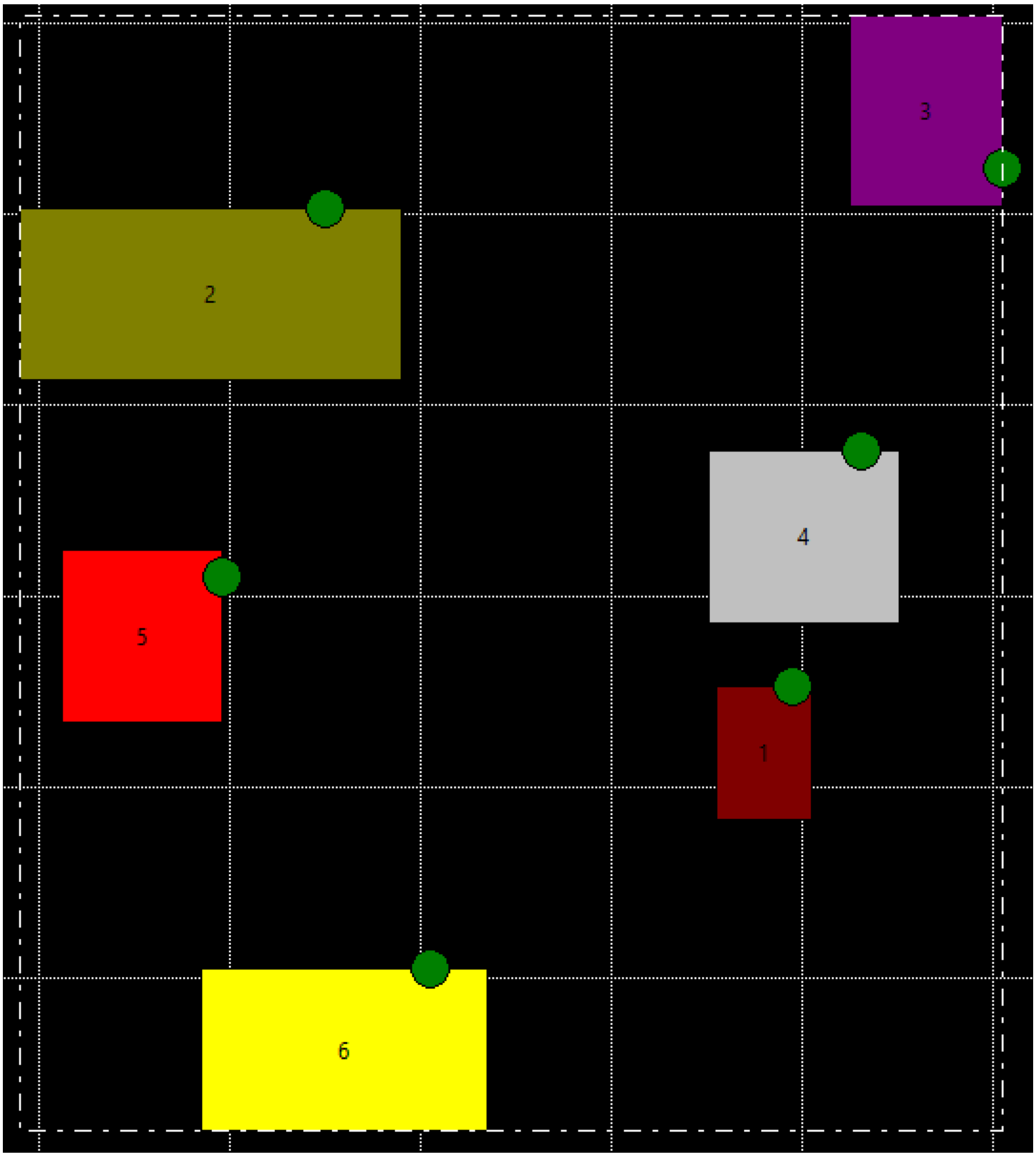

Figure 2, Example of random generated initial layout (Before optimization)_2

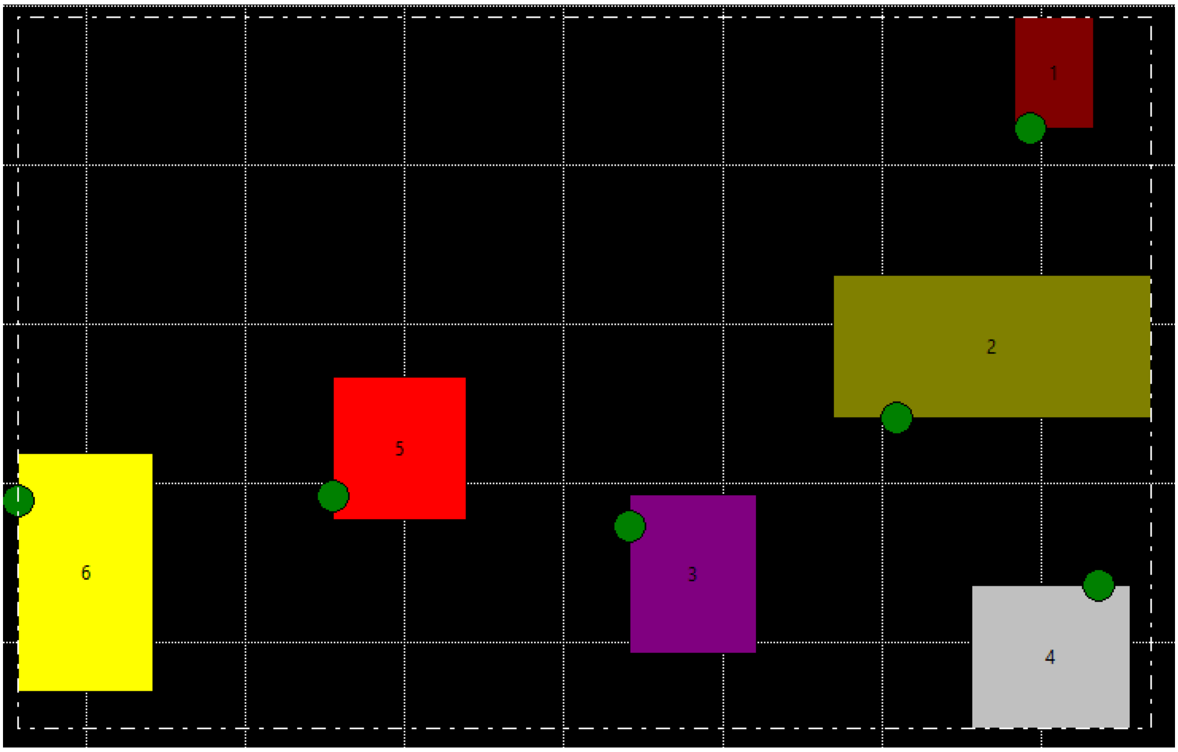

Figure 3, Example of random generated initial layout (Before optimization) _3

4.3.2 Optimized layouts simulations

Here a continuous encoding to layout is used where each room corresponds to the sequence of activities movements shown in Table 2 and Table 3. The rooms are randomly placed in the available set space as shown above, with, their dimensions and their locations in the space according to x and y-axis. The simulation is run with the settings shown in Equation 1, with the following results shown in Figure 4, Optimized solution_1Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16 and Figure 17. In tables Table 4, Table 5, Table 6 and Table 7 it's possible to see the distance between the rooms matrix, shown at first iteration and 500th iteration.

Figure 5, Figure 7, Figure 9, Figure 11, Figure 13, Figure 15 and Figure 17 shows the sum of the distances matrix between the rooms and the probability matrix in Table 3

Table 4, Table 5, Table 6 and Table 7 shows the distance matrix between rooms on the first iteration and on the 500th iteration.

Equation 1, PSO Settings:

'self.PSO(MaxIter = 500,PopSize = 100 ,c1 = 0.7 ,c2 = 1.5,w = 1,wdamp = 0.99))'

To prevent the particles from falling into local overlapping traps it's embedded a local search algorithm into PSO to give more satisfactory solutions.

At the end of an iteration of PSO, the global best found is improved with the local search algorithm. A Swap operator generates a new location solution from current candidate solution by making a slight change in it. This step is repeated while we find better solution. After each swap, the solution is evaluated again and the new objective function value is compared with the global best one. If a better solution is found, the global best solution will be replaced.

The major challenge when solving layout problems with PSO algorithm is that the room placement and their form is a highly constrained engineering problem whereas PSO does not have a mechanism to deal with constrained problems.

According to the study of (Chraibi, et al., 2016) they state the following regarding methods for dealing with constrains “In the literature, there are different ways of constraint handling in PSO. He et al. (2004) used a constraint handling method called the fly-back mechanism to maintain a feasible population. They also extended the standard PSO algorithm to handle mixed variables using a simple scheme. Zahara & Hu (2008) proposed embedded constraint handling methods combined with the Nelder-Mead simplex search method. Their method included the gradient repair method and constraint fitness priority-based ranking method. KulturelKonak & Konak (2011) used a construction heuristic to generate acceptable layout structures and a penalty function to penalize solution infeasibilities because of department shapes and layout dimensions. In order to avoid premature convergence, Cagnina et al. (2011) used a dynamic-objective constraint-handling method and an e-constraint constrained differential evolution. “

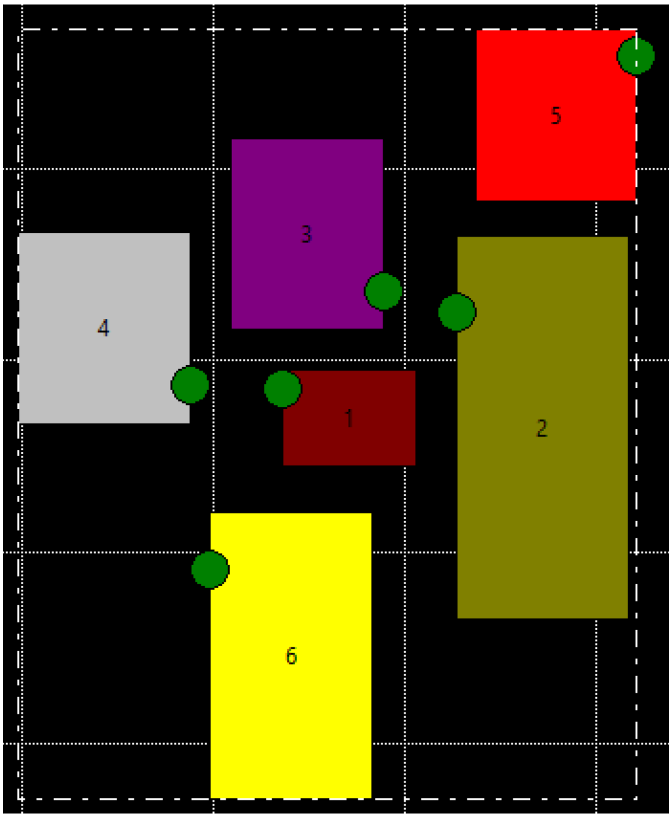

Figure 4, Optimized solution_1

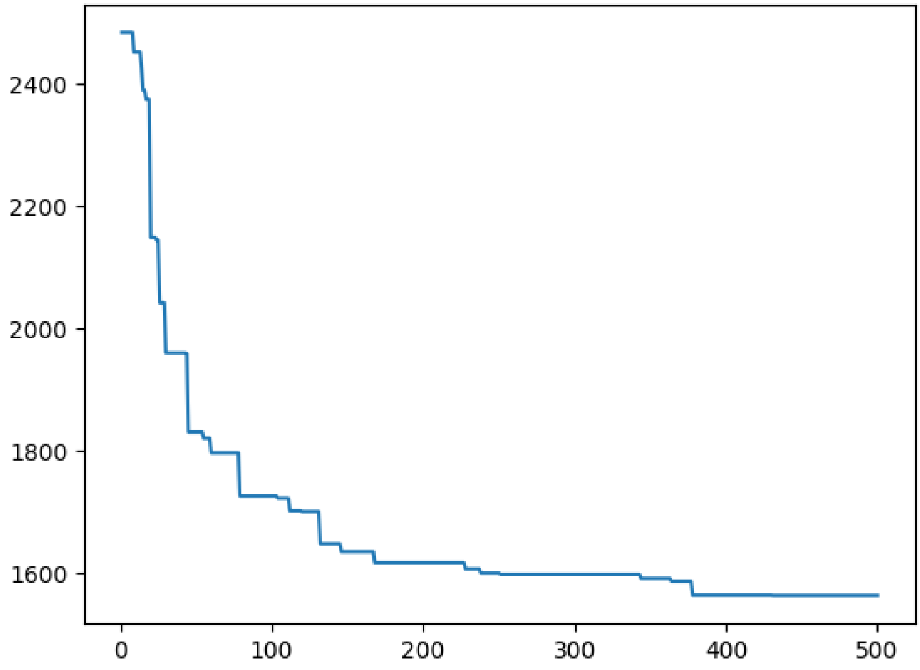

Figure 5, Optimized solution graph_1

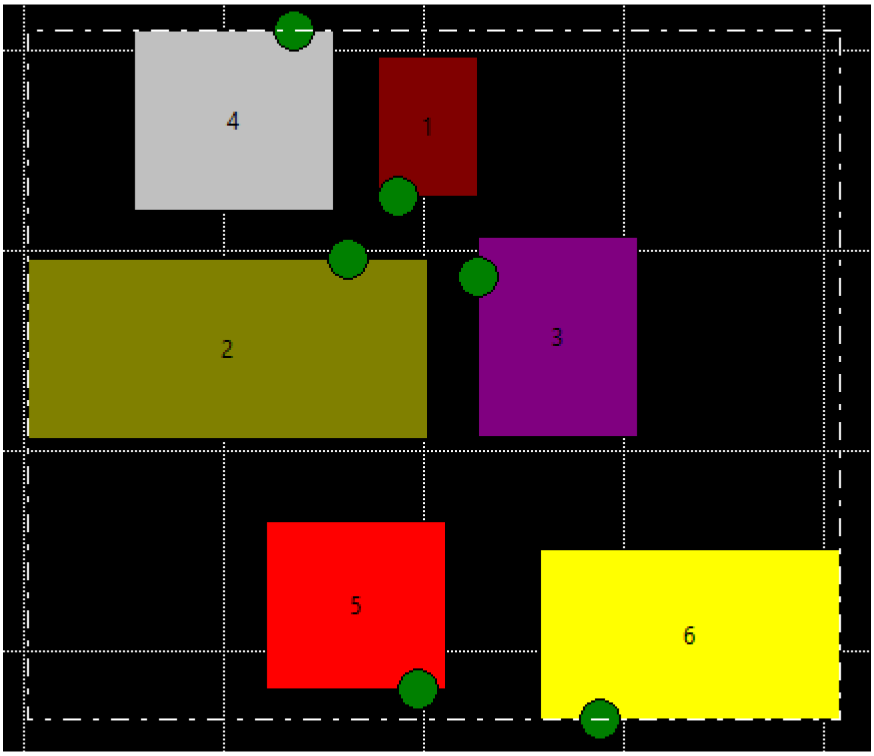

Figure 6, Optimized solution_2

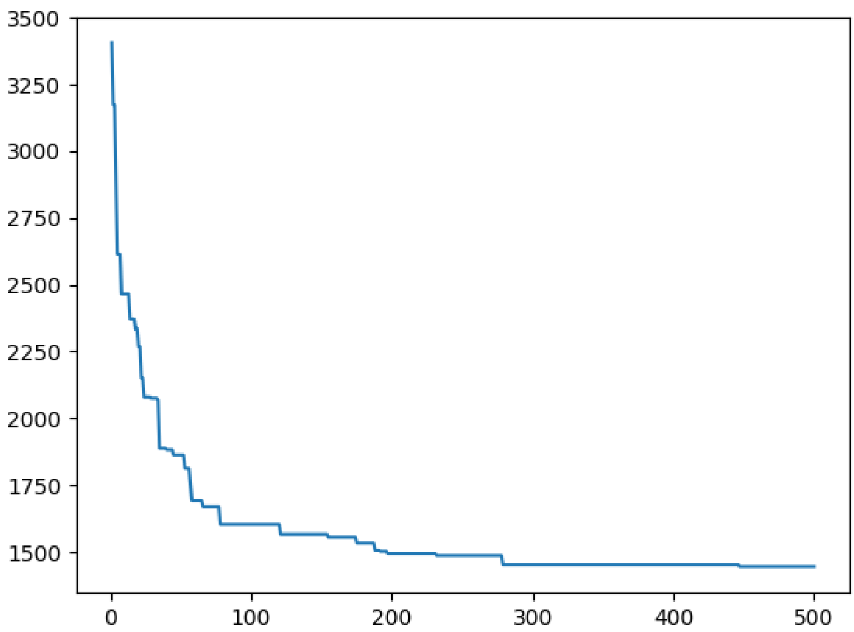

Figure 7, Optimized solution graph_2

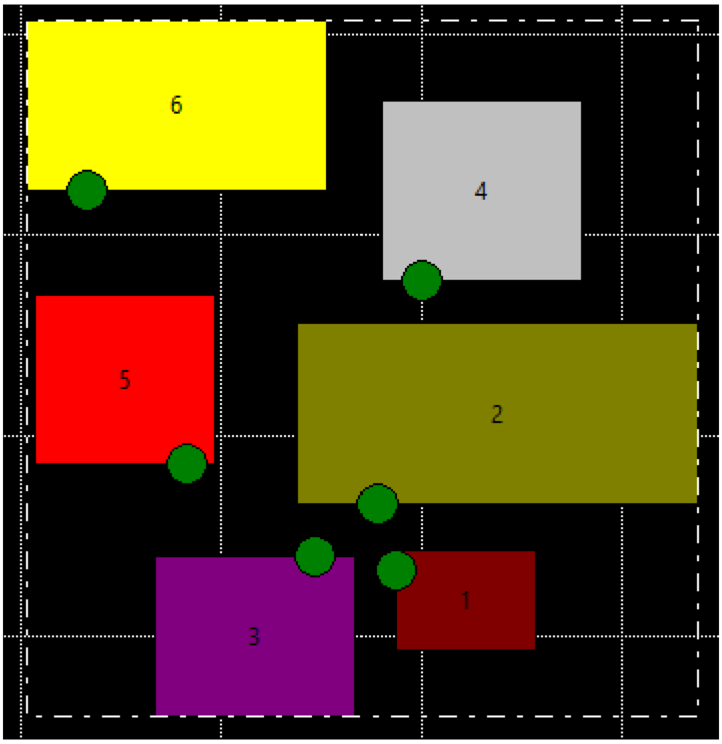

Figure 8, Optimized solution_3

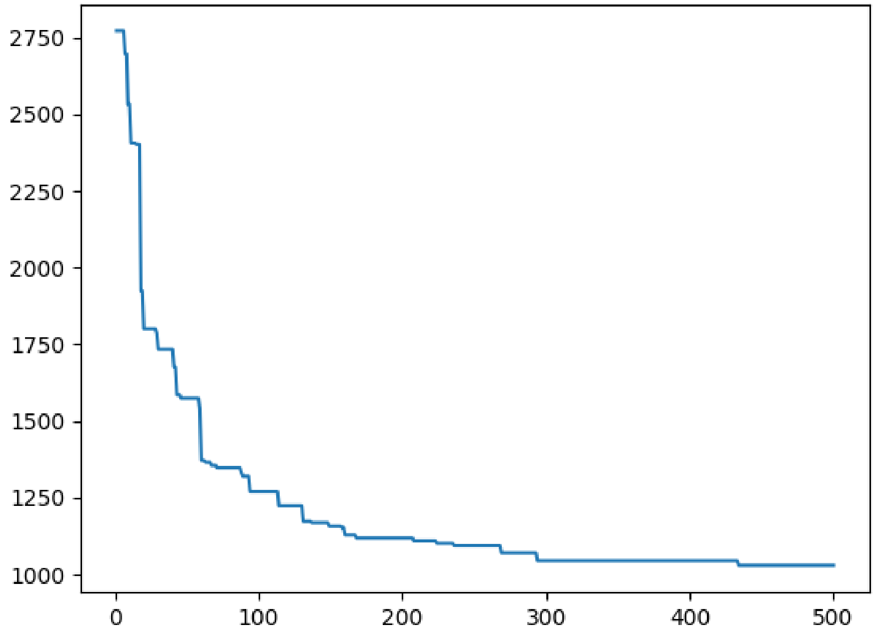

Figure 9, Optimized solution graph_3

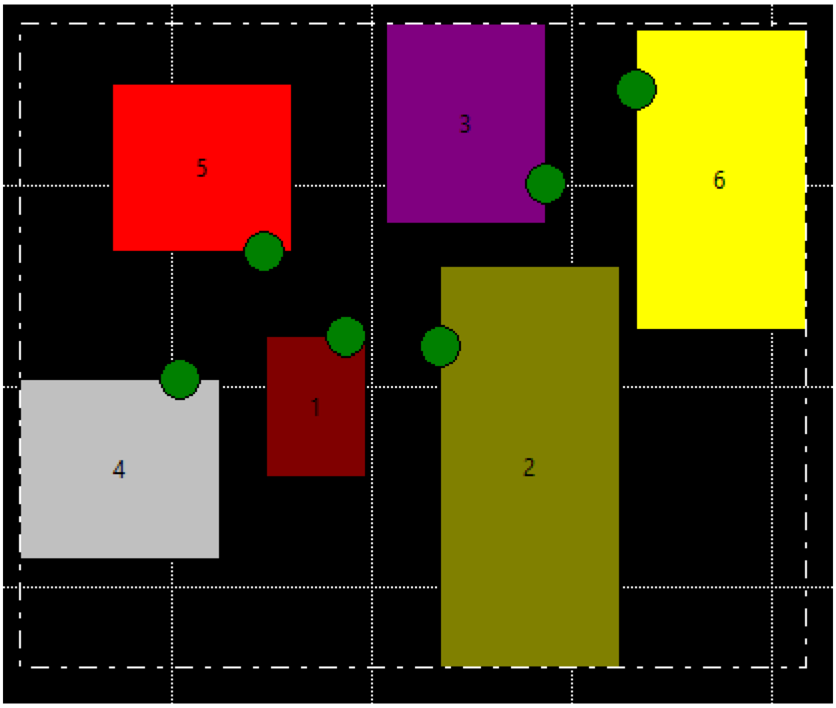

Figure 10, Optimized solution_4

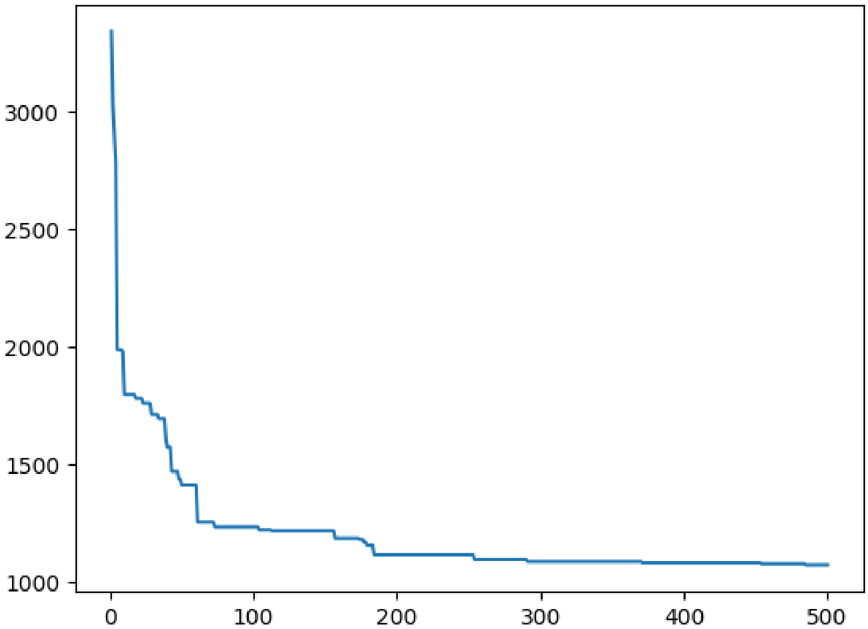

Figure 11, Optimized solution graph_4

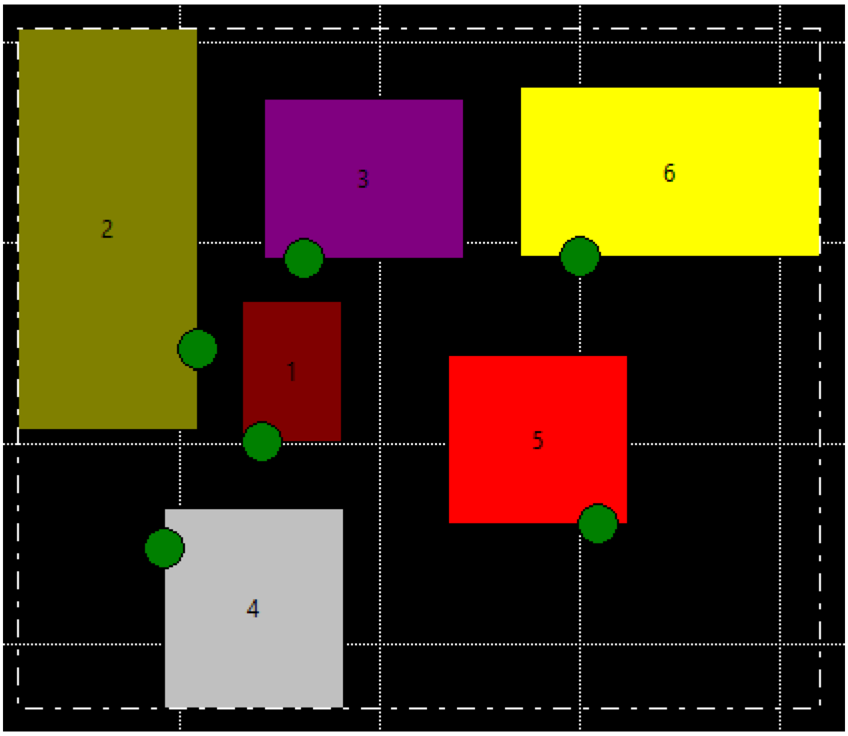

Figure 12, Optimized solution_5

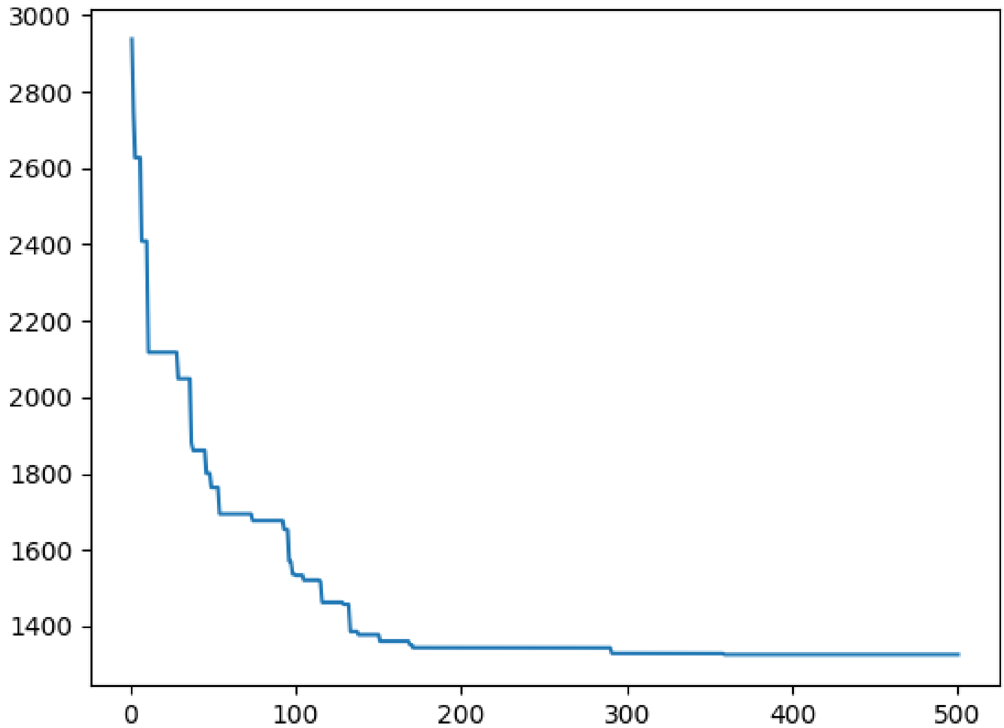

Figure 13, Optimized solution graph_5

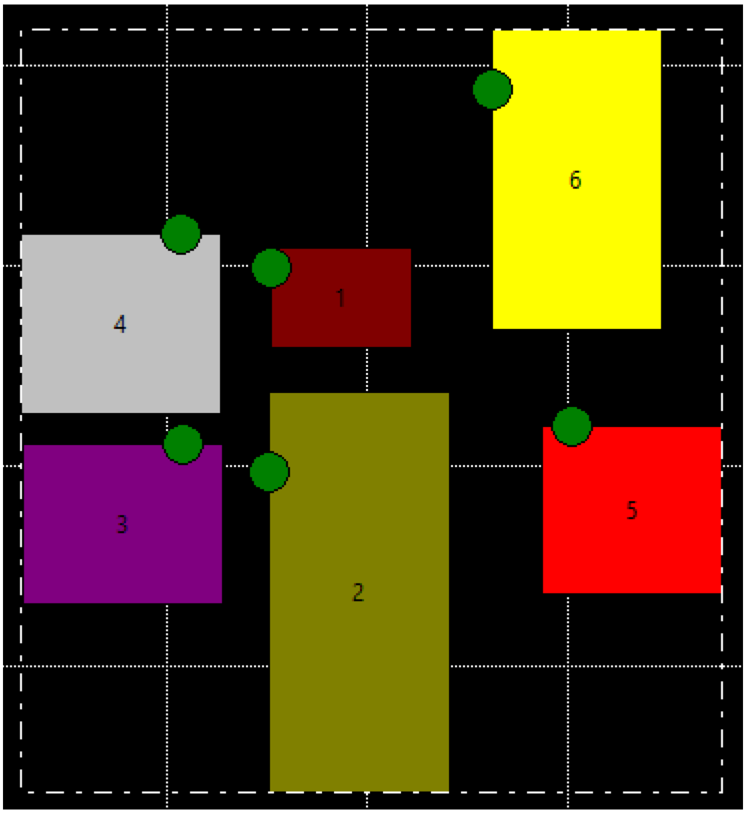

Figure 14, Optimized solution_6

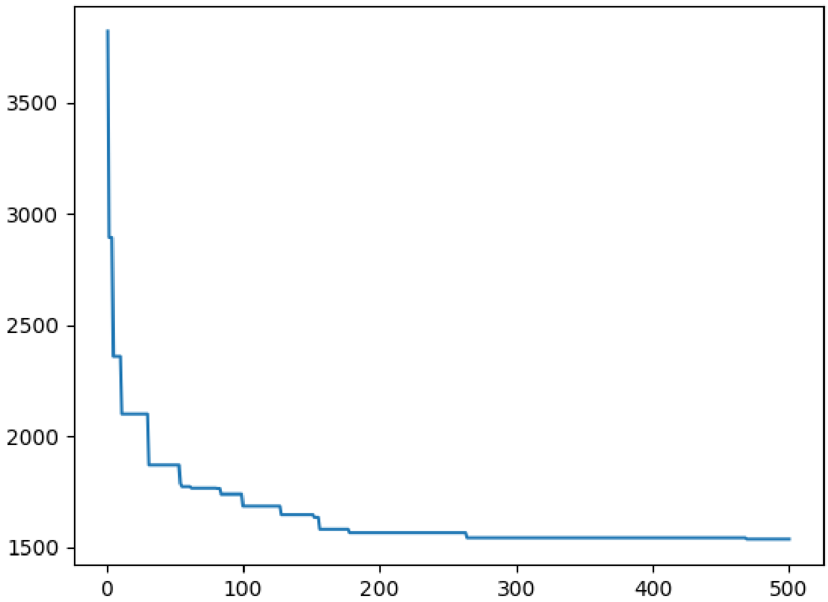

Figure 15, Optimized solution graph_6

Table 4, Distance matrix iteration 1 Simulation_6

0	134	393	275	229	609
134	0	264	320	205	548
393	264	0	452	297	422
275	320	452	0	155	435
229	205	297	155	0	382
609	548	422	435	382	0

Table 5, Distance matrix iteration 500 Simulation_6

0	102	98	48	169	142
102	0	45	127	152	221
98	45	0	105	194	235
48	127	105	0	217	171
169	152	194	217	0	173
142	221	235	171	173	0

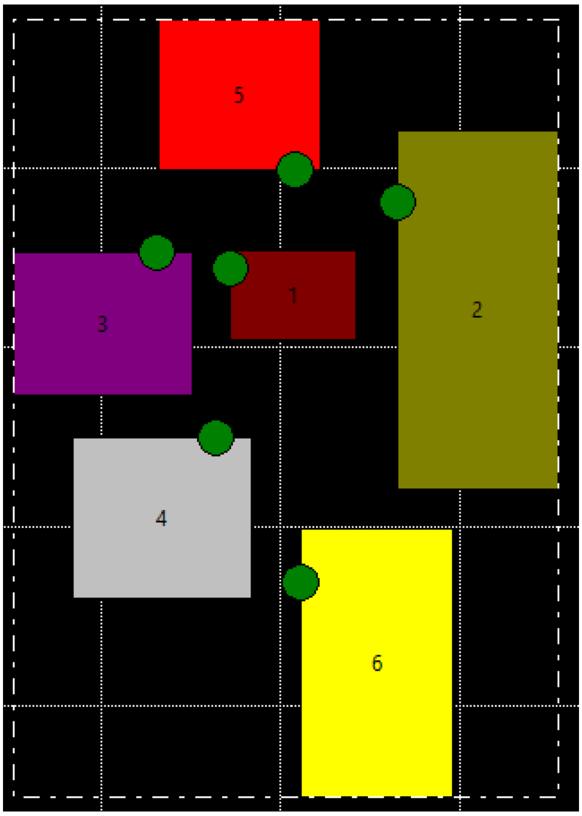

Figure 16, Optimized solution_7

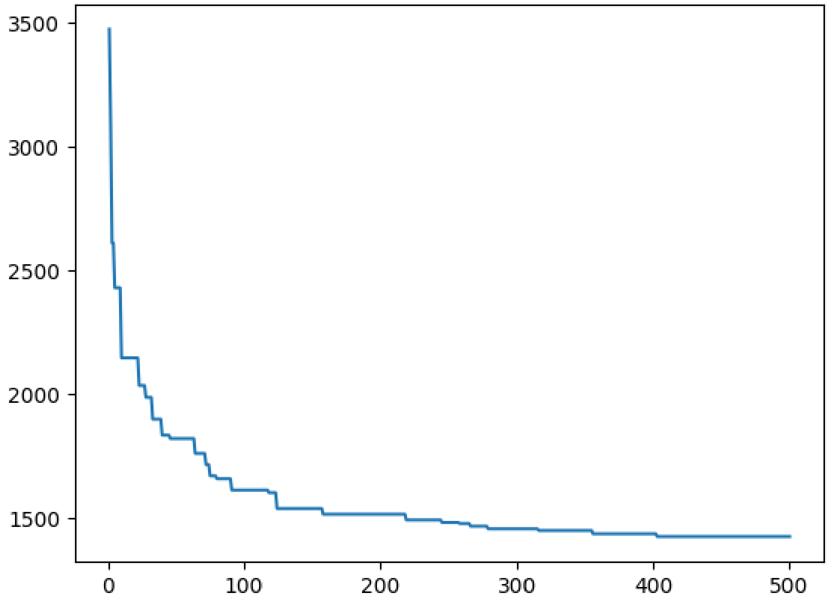

Figure 17, Optimized solution graph_7

Table 6, Distance matrix iteration 1 Simulation_7

0	142	286	209	355	213
142	0	149	322	289	354
286	149	0	469	236	496
209	322	469	0	564	178
355	289	236	564	0	510
213	354	496	178	510	0

Table 7, Distance matrix iteration 500 Simulation_7

0	62	102	91	74	102
62	0	159	46	63	138
102	159	0	169	131	154
91	46	169	0	42	182
74	63	131	42	0	175
102	138	154	182	175	0

5 Implementation of optimized layouts into BIM

Dynamo is a simulation language based on visual programming and originally as an add-on for BIM in Revit. Now is a platform, enabling designers to explore visual programming, solve practical design problems and automate, and make their own optimization of processes in Revit visually. In addition, it has transformed to a platform within Revit and not only as a add-on. Also, it can be downloaded and run in either stand-alone "Sandbox" mode or as a plug-in for other software like, FormIt or Civil 3D.

In Dynamo, we connect elements together to define the relationships and the order of actions that could use custom algorithms, and elements within the program host, as Revit. As example, is to rotate a group of columns in Revit, which in the program itself has to be done by each instance, while visually programming in Dynamo all the columns could be rotated automatically.

In this master thesis, the software for handling BIM has been Revit. Revit is building information software from Autodesk used by various engineering field, architects and contractors, and allows it users to create, edit, exchange and review 3D BIM models.

5.1 Dynamo script

The visual programming script for this study is performed in the following way: The whole script shown in annex c.

1. Output from the algorithm is transformed into CSV files, read into dynamo.

Figure 18, Dynamo Step-1 – read input from PSO

Second step is to read this data into separate list for each of the rooms, shown in Figure 19. The list contains the x and y coordinate for the center point for each room, and x and y coordinates for two of the corner points.

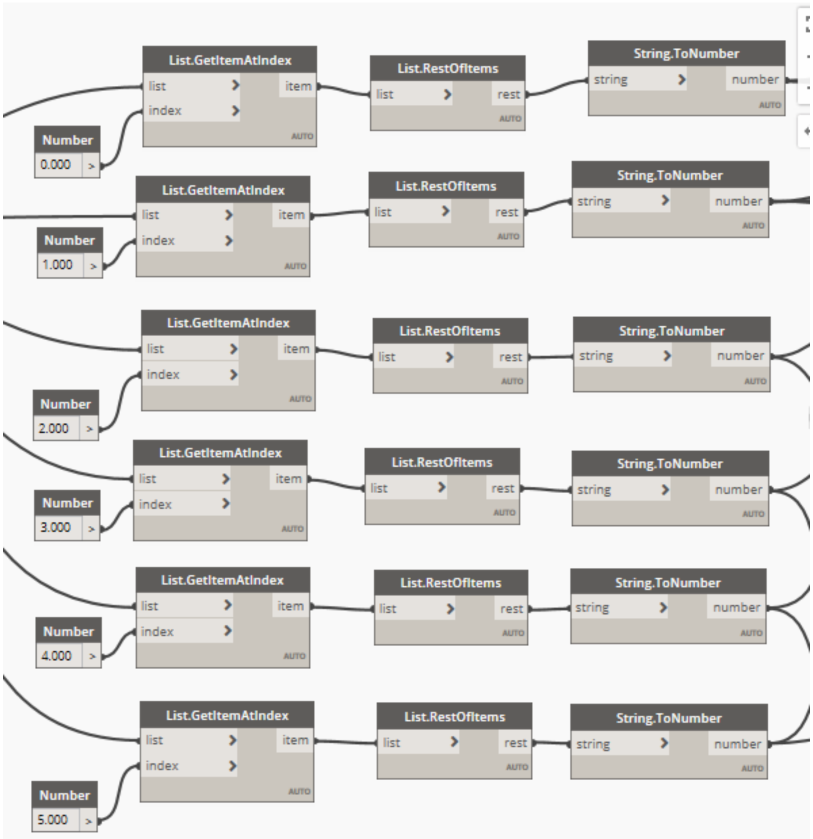

Figure 19, Dynamo step-2 - creation of lists for rooms, center point and 2 corner points

Third step is to do the equal for the same for the outline for the area, shown in Figure 20

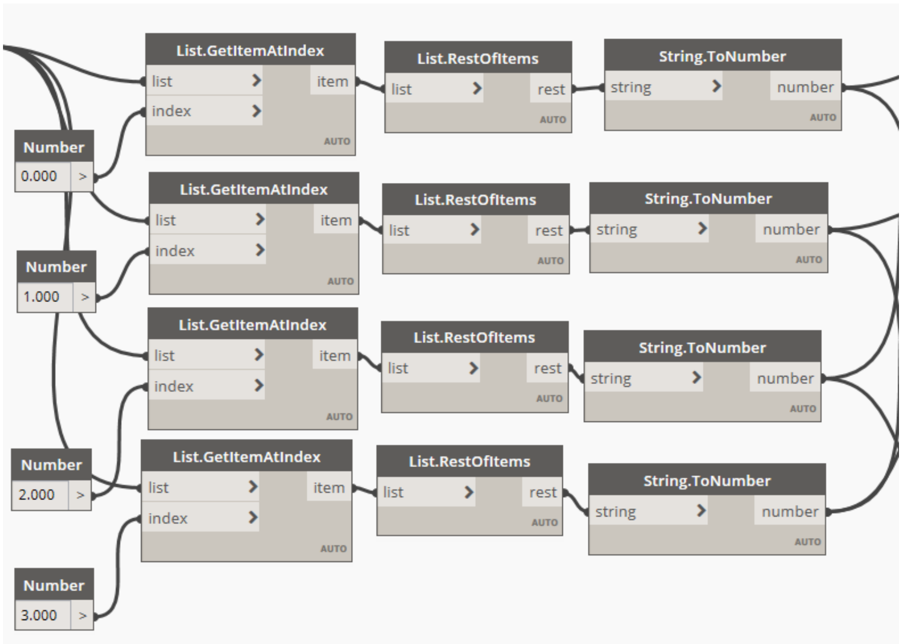

Figure 20, Dynamo step-3 - List of outline border

Fourth procedure the list for the rooms (Figure 19) is fed to a function calculating the distance between rooms in the x and y direction. In addition, the x and y coordinates are created for the 2 corner points and center points. Coordinates for 2 corner points not used further. In addition, since we only have two corner points, which used to calculate the width and depth of the rooms, we have created a coordinate system from the center of rooms to place the walls rectangle correct. I.e. that the rooms are created from a 3 point perspective. See Figure 21.

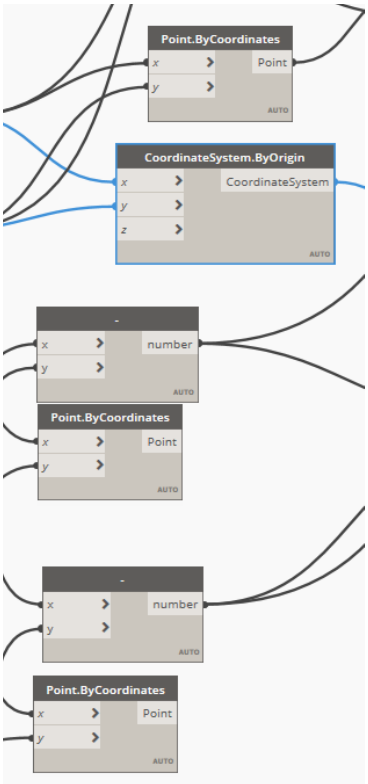

Figure 21, Dynamo step-4 - distance between x and y in the axis direction and coordinates of the 2 corner points

Fifth step is to produce x and y coordinates for every corner point, and lines for each side and rectangle. The rectangle is used further, while the lines are not. See Figure 22.

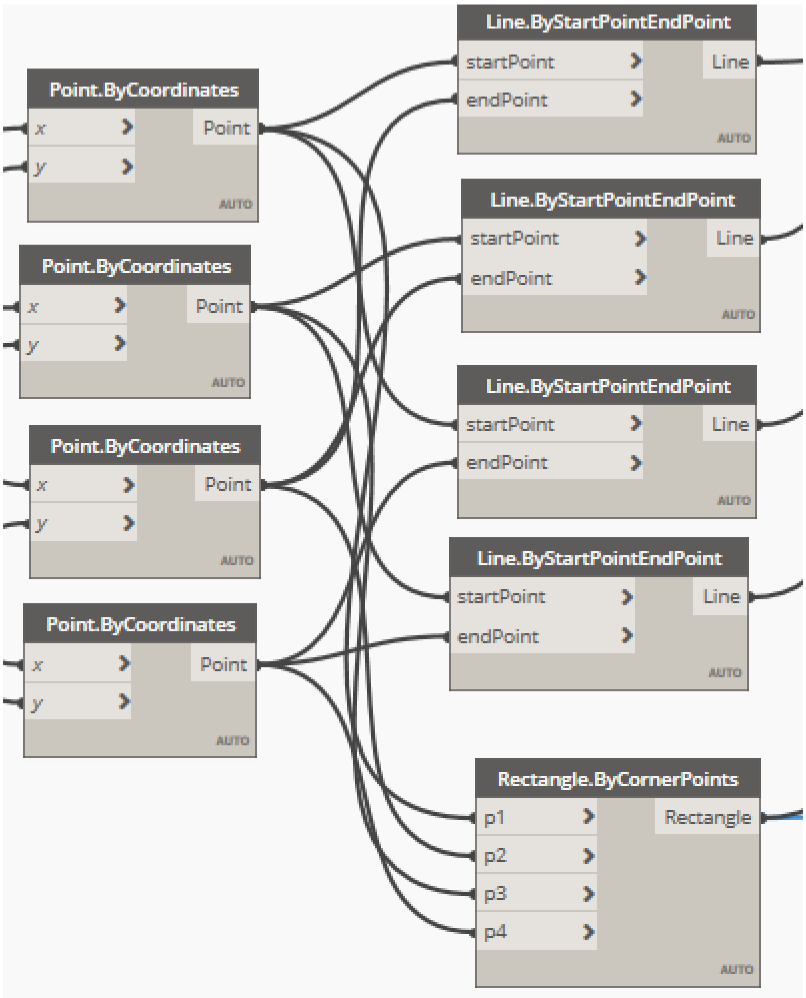

Figure 22, Dynamo step-5 - Points, lines and rectangle for outline borders

This script last, and sixth in order is the creation of floors and walls for the outline and the individual rooms. See Figure 23.

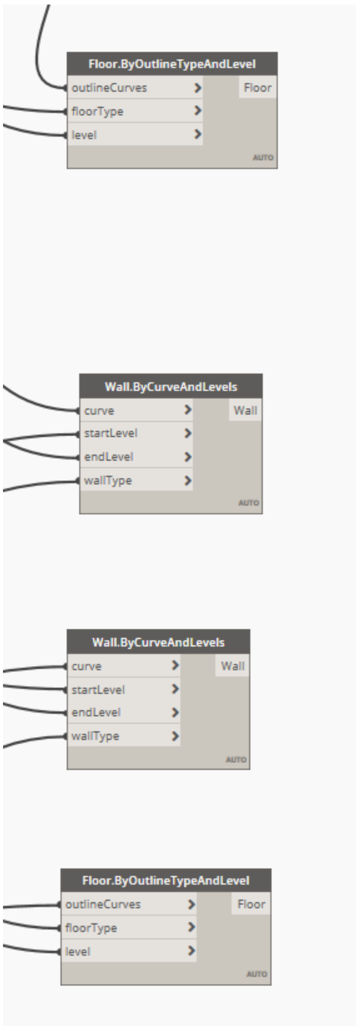

Figure 23, Dynamo step-6 - floors and walls

5.2 BIM using Dynamo

A number of simulations has been carried out to create a BIM model from the optimized 2D layout from PSO algorithm. The sequence is as follows, PSO output in form of comma separated values (CSV) functions as input to Dynamo. Dynamo Automa creates a BIM model in Revit.

The PSO algorithm was set to run 10 iterations, creating a 2D layout output which has significant distance between the rooms. The results shows that the methodology created perform as expected. Figure 24, Figure 26, Figure 28 shows the optimized PSO 2D layout and Figure 25, Figure 27, Figure 29 shows the automated creation of a BIM through dynamo script represented in in Revit. Be noted that the BIM are mirrored, and an explanation for this could be that PSO views are from underneath while the BIM is from above. The number denotation in the figures shown that the number _8 is the equivalent PSO layout and BIM model.

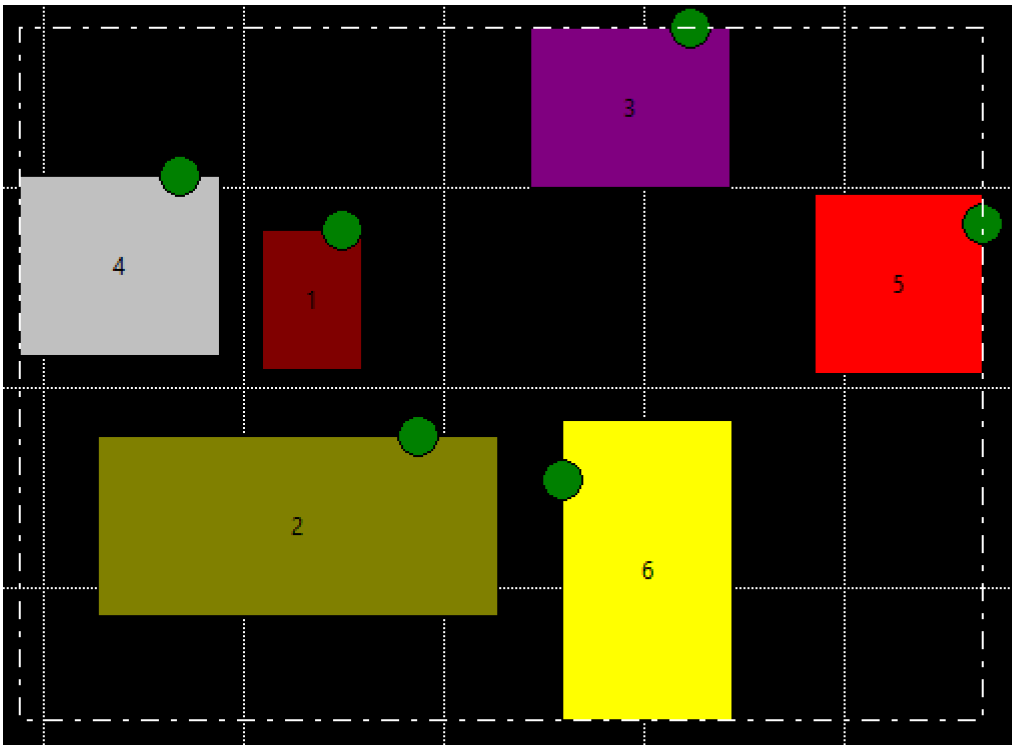

Figure 24, Layout PSO_8

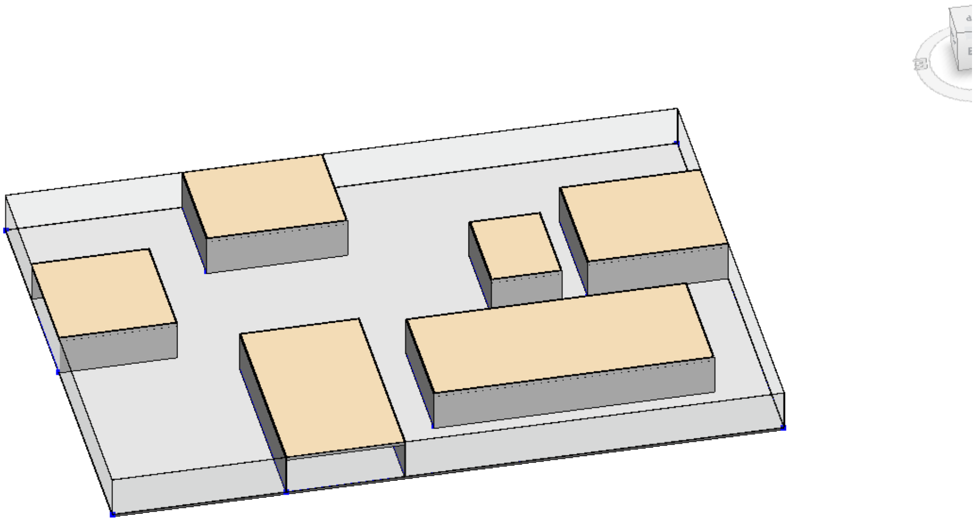

Figure 25, BIM model from Revit_8

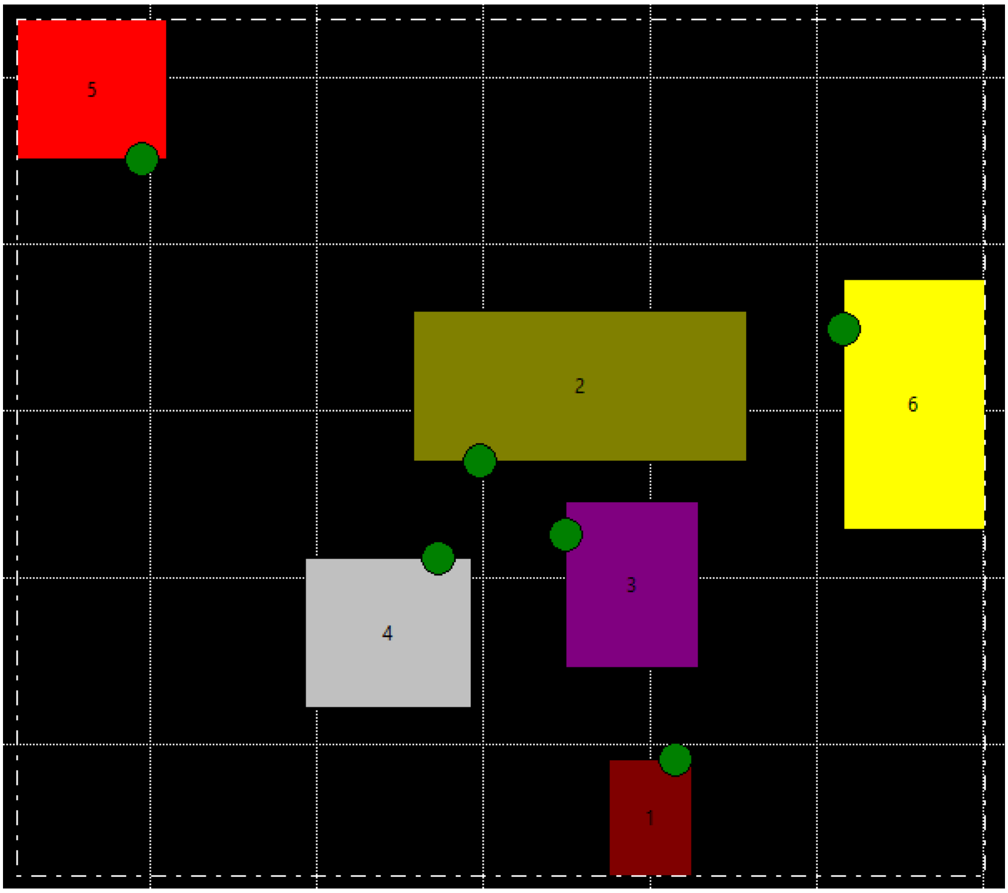

Figure 26, Layout PSO_9

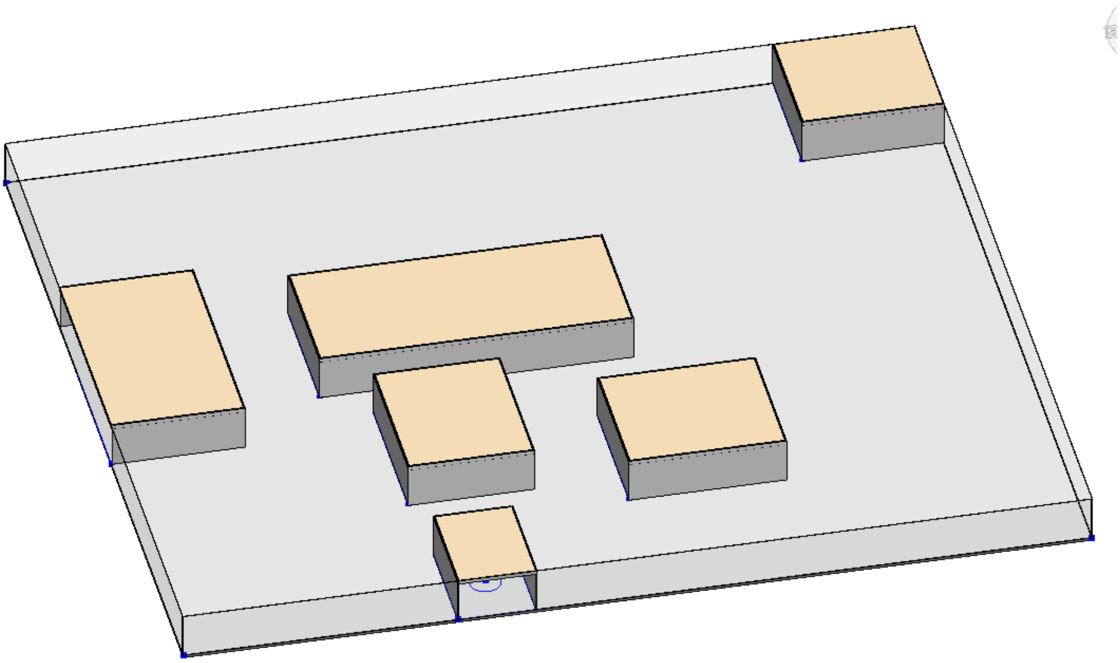

Figure 27, BIM model from Revit_9

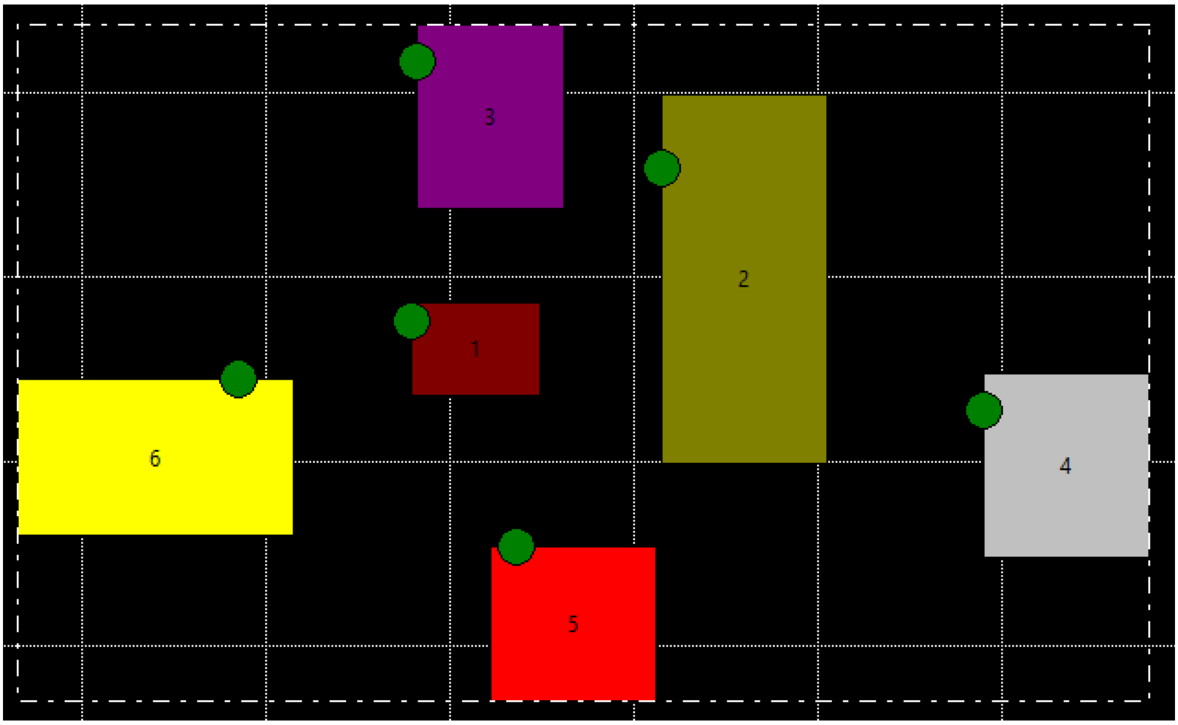

Figure 28, Layout PSO_10

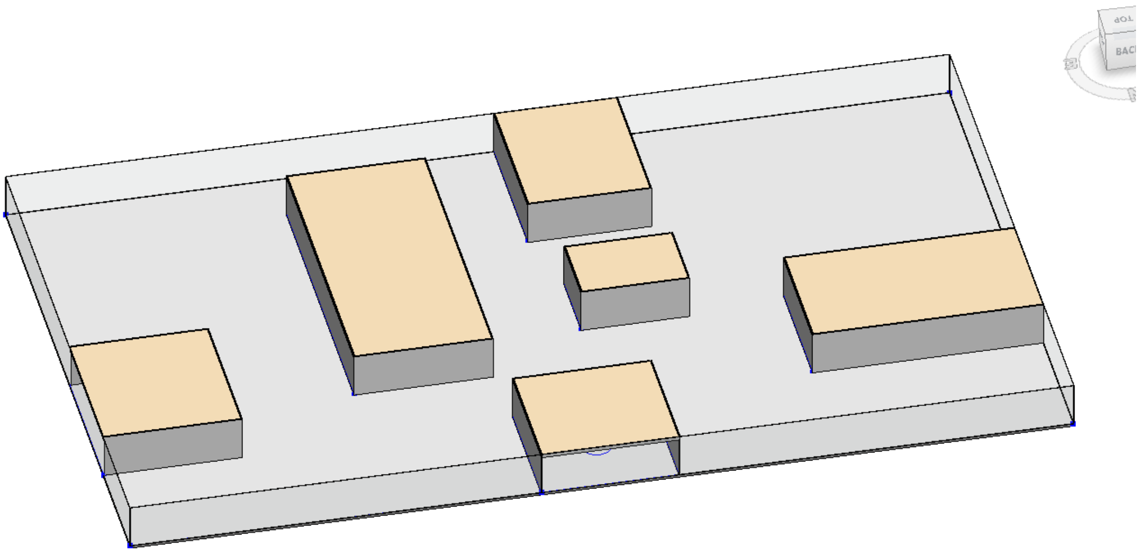

Figure 29, BIM from Revit_10

6 Budget summary

The expenses for this study are further detailed in the “Budget Summary – Bjorn Hogmo.pdf.” Total expenses amounted to €25 453 for this methodology for creating an automated BIM model from PSO algorithm.

7 Analysis and assessment of environmental implications

The construction industry has a mayor impact on the environment, and according to some studies the industry is responsible for up to 50 % of climate change. In this master thesis the focus is on developing a 'new way' of creating a phase in the design process of a construction project within healthcare facilities. The effect a design phase in itself on climate change is limited in my opinion, but improvement in effectiveness of a building could have I think could have some effect.

Using the 17 'Sustainable goals' from UN, in this thesis the aim is to create a small effect within the following goals:

3. Good health and well-being

9. Industry, innovation, and infrastructure

10. Climate action

Good health and well-being

One positive effect of creating a new and optimized layout when creating and establish new healthcare facilities is that it could be built in a manner that could improve the pathways of patients, staff, goods or similar. If the facilities are better for the patients, this 'new method' for a design phase could give an improvement of their health, and especially the patient experience in a healthcare facility.

Another effect, could be more effective good delivery and transport within a facility

Industry, innovation and infrastructure

As this suggested new or improved approach in the design phases for a healthcare facility, time and man labor could be reduced in the phase, and the health infrastructure could benefit on better optimized health care facilities for their purpose or for crate a more or better streamlined pathways for patients or staff for example.

Climate action

This improvement in early design phase could result in better built healthcare facilities, and as a effect reduce the need for creating new facility or hospital. Without any reference, if in 10 years, one less facility is needed, it would save resource use, and $CO2$ emissions from a construction project.

8 Discussion and Conclusions

Several studies solving LP by the use of algorithms. The research studied in this master thesis shows the use of GA, PSO, PDFA-PSO, NSGA-II algorithms and use of mathematical models to solve and optimize HLP. Generally, their approaches using actual clinic or hospital data to perform such an optimization simulation for generating a layout solution based on optimization parameters.

Traditional approach in a construction project is to establish a BIM model with available information, normally collected through extensive data collection from users combined with stakeholders' requirements. The challenge by the traditional methods, is that data collection is a time consuming and labor-intensive approach, and the creation of BIM model requires several designers and takes time. In addition, to achieve good results, the method is heavily reliant on the experience of the stakeholders representants and the experience of the design suppliers.

EHR data has become more available for hospitals, but no frameworks exist in the literature to integrate or perform a whole new hospital or facility design or to use such knowledge in the preliminary phases of design. Trending approaches shows the use of such data to generate methods of simulations to achieve optimized suggestion for layout, in 2D. The approach presented in this paper crate a methodology for transforming and interpretating EHR data with optimization algorithms, in this case PSO algorithm which creates an optimized 2D layout, to a 3D BIM model through the visual programming in Dynamo.

For this thesis, EHR data have not been available, but similar data has been created as in other researches. This data simulates the use of EHR data, and function as input for the optimization algorithm. The algorithm in use is a PSO algorithm, modified with regards to the used input and output to create data that the scripting could interpretate. The output was denoted into CSV files with x and y coordinates for their placement in the 2D plane. Dynamo scripting interpretated this data to coordinates readable by BIM software, and transformed to accommodate values in the z direction as well (heights). The scripting then transforms the results into BIM software, which creates a well visualized 3D BIM model.

The proposed approach could create optimized solutions, and it is possible to simulate and create several proposals within days. These optimized layouts could be transformed into high quality visualized 3D BIM model software and give valuable start of a preliminary phase, giving the project organization a valuable discussion point with the expert users, stakeholders, and experienced designers. The method has the potential to eliminate or reduce the time consuming and labor-intensive traditional method for data collection of a preliminary phase and demanding creation of BIM model.

Future work is to expand all phases of methodology in this thesis. The PSO algorithm expanded for other inputs and fitted for real life EHR data, or to accommodate staff movements. "The main difference between a patient pathway and a nurse pathway is that the nurse does not have defined starting and finishing points in the pathway. In a regular shift, a nurse can traverse between many patient rooms and stations, and this can vary between one day and the other." In addition, further research on combining the used algorithm with other algorithms.

Such an expansion in the optimization algorithm also leads to further adjustments and expansion of the Dynamo scripting.

Therefore, it is believed that the ideal future work will be to use actual clinic data research and adjust this methodology to a real-life scenario.

9 References

Alavi, H., Forcada, N., Bortolini, R. & Edwards, D. J., 2021. Enhancing occupants' comfort through BIM-based probabilistic approach. *Automation in Construction,* Volume 123.

Arnolds, I. & Nickel, S., 2013. Multi-period layout planning for hospital wards. *Socio-Economic Planning Sciences,* 47(3), pp. 220-237.

Arnolds, I. & Nickel, S., 2015. Applications of Location Analysis - Layout Planning Problems in Health Care. *Springer.*

Arnolds, I. V. & Gartner, D., 2018. Improving hospital layout planning through clinical. *Annals of Operations Research,* Volume 263, pp. 453-477.

Bendjoudi, 2018. *PyFLP-PSO.* s.l.:Gitbub - Missipsa06.

buildingSMART, 2022. *Artificial Intelligence in BIM and renovation.* [Online] Available at: https://www.buildingsmart.org/artificial-intelligence-in-bim-and-renovation/ [Accessed 16 01 2022].

Charabi, A., Osman, I. H. & Kharraja, S., 2018. Adaptive layout for operating theatre in hospitals: Different mathematical models for optimal layouts. *Annals of Operations Research,* 272(1-2), pp. 1-35.

Chraibi, A., Kharraja, S., Osman, I. H. & Elbeqqali, O., 2016. A Particle Swarm Algorithm for Solving the Multi-objective Operating Theater Layout Problem. *IFAC-PapersOnLine,* 49(12), pp. 1169-1174.

Gai, L. & Ji, J., 2017. An integrated method to solve the healtcare faciltiy layout problem under area constraints. *Journal of Combinatorial Optimization,* 37(1), pp. 1-19.

Halawa, F., Khasawneh, M. T. & Chalil Medathil, S., 2021. Integrated framework of process mining and simulation–optimization for pod structured clinical layout design. *Expert Systems With Applications,* Volume 185.

Hamidavi, T., Abrishamo, S. & Hosseini, R., 2020. Towards intelligent structural design of buildings: A BIM-based solution. *Journal of Building Engineering,* Volume 32.

Helber, S. et al., 2016. A hierarchical facility layout planning approach for large and complex hospitals. *Flexible Services and Manufacturing Journal,* 28(1-2), pp. 5-29.

Howe, M. K., 2017. *The Promise of Generative Design.* [Online] Available at: https://www.world-architects.com/en/architecture-news/insight/the-promise-of-generative-design
[Accessed 16 01 2022].

Huo, J., Liu, J. & Gao, H., 2021. An NSGA-ii algorithm with adaptive local search for a new double-row model solution to a multi-floor hospital facility layout problem. *Applied Science,* 11(4), pp. 1-21.

Indreråk, T., 2019. *STRATEGISK TEKNOLOGINOTAT,* Trondheim: Sykehusbygg.

Ito, M. & Suzuki, M., 2022. Bed Management for Inpatients Using Particle Swarm Optimization. *IIAI Letters on Informatics and Interdisciplinary Research,* Volume 1.

Rubel, Z., 2022. *Hospital Design and Construction* [Interview] (22 08 2022).

Shi, Y. & Eberhart, R. C., 1998. Parameter selection in particle swarm optimization. In: *Evalutionary Programming VII: Proc. EP 98.* New York: Springer-Verlag, pp. 591-600.

The Dynamo Primer, 2022. *Dynamo.* [Online] Available at: https://primer.dynamobim.org/index.html
[Accessed 03 12 2022].

Uzila, A., n.d. *Complete Step-by-step Particle Swarm Optimization Algorithm from Scratch.* [Online]
Available at: https://towardsdatascience.com/complete-step-by-step-particle-swarm-optimization-algorithm-from-scratch-74471d064f91
[Accessed 29 12 2022].

Vahdat, V., Namin, A., Azghandi, R. & Griffin, J., 2019. Improving patient timeliness of care through efficient outpatient clinic layout design using datadriven simulation and optimisation. *Health Systems,* 8(3), pp. 162-183.

Wehn, A., 2018. *Digitalisering skaper nytenkning om Sykehus.* [Online] Available at: https://www.cowi.no/innsikt/digitalisering-skaper-nytenkning-om-sykehus [Accessed 15 12 2022].

Wen, Y., Tang, L. & Ho, D., 2020. A BIM-based space-oriented solution for hospital facilities management. *Emerald Insight.*

Zabin, A., Gonzàles, V. A., Zou, Y. & Amor, R., 2022. Applications of machine learning to BIM: A systematic literature review. *Advanced Engineering Informatics,* Volume 51.

Zhao, C., Yang, J., Xiong, W. & Li, J., 2021. Two Generative Design Methods of Hospital Operating Department Layouts Based on Healthcare Systematic Layout Planning and Generative Adversarial Network. *J. Shanghai Jiao Tong Univ. (Sci.),* 26(1), pp. 103-115.

Zhao, Y., 2013. *Evidence based design in healthcare: Integrating user perception in automated space layout planning,* s.l.: Loughborough University.

10 Acknowledgments

The author has closely been cooperating with the mentor of this report, Hamidreza Alavi and own him the big and great thanks for the support and guidance during the development of the report.

In addition, the author thanks his friend and mentor Ahmet Yeter for his support in understanding and learning some Python coding and programming.