Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Zahra Khoshnevis
Student number	

Studio		
Name / Theme	BT Graduation Studio	
Main mentor	Serdar Asut	Design Informatics
Second mentor	Stijn Brancart	Structural Design
Argumentation of choice of the studio	The field of Design Informatics encompasses Swarm Robotics and Robotic Construction, while the Structural Design aspect of this subject focuses on the dynamic construction sites and assembly sequences.	

Graduation project	
Title of the graduation project	Enabling Construction Autonomy on Dynamic Building Sites through Implementation of Swarm Robotics.
Goal	
Location:	Not Specified
The posed problem,	In 2020, the global construction industry was valued at $10.7 trillion, with projections indicating a 42% expansion to $15.2 trillion by 2030 (Oxford Economics, 2021). This growth positions the construction sector as a significant driver of economic expansion, with the global output expected to reach $13.3 trillion by 2025 (Oxford Economics, 2021). Despite construction industry’s size and value, automation in this field remains a challenge unlike other sectors (Khaluf et al., 2020; Lieveloo, 2023). Factors such as labor shortages, high safety risks (Xiao, Chen, and Yin, 2022), and the increasing demand for sustainability, efficiency, and productivity drive the urgent need for automation in construction (Pan et al., 2018). The emergence of new technologies has led to advanced automation in construction tasks, reducing human involvement. However, the unique characteristics of the construction process necessitate the adoption of new automation methods (Dias et al., 2021). Robotic Construction has emerged as a promising solution to address these

	challenges, offering significant improvements in productivity and safety (Pan et al., 2018). Robotic Construction introduces robotic construction equipment and customized robots, with potential for integration into structures in the near future (Allwright, Bhalla, and Dorigo, 2017). Swarm Robots, as a sub-category of Robotic Construction, offer theoretical solutions to escalate automation in construction, drawing inspiration from social insect behaviors. However, these concepts have yet to be fully applied to industrial robots in the construction industry (Liyanage and Fernando, 2021). In this thesis, the aim is to enabling Construction Autonomy on Dynamic Building Sites through Implementation of Swarm Robotics as a subset of the Robotic Construction.
research questions and	“**How can Swarm Robots enable construction autonomy (using collective perception) on a dynamic construction site?”** Sub- Questions i. How do swarm robots detect dynamic changes in a construction site using collective perception? ii. How do swarm robots respond to real-time changes in a construction site to maintain construction autonomy? iii. In what ways do swarm robots collaborate and share information to enhance their collective perception on a dynamic construction site? iv. How can the autonomy of swarm robots enable the efficient construction assembly sequence in the face of continuous changes in the construction environment? v. What navigation and obstacle avoidance mechanisms can swarm robots employ to ensure autonomy in a dynamically changing construction site?
design assignment in which these result.	Objectives: • Developing a three-stage workflow for the adaptive behavior of Swarm Robots in a dynamic construction site. • Configuring a virtual simulation to replicate Swarm Robots' adaptive behavior within a dynamic construction environment. • Establishing a virtual experiment for the validation stage.
[This should be formulated in such a way that the graduation project can answer these questions.	

The definition of the problem has to be significant to a clearly defined area of research and design.]

Process

Method description

- Literature Review

A comprehensive literature review will be conducted, delving into key topics:
Multi- Agent Robotics Systems
Swarm Robots and Swarm Intelligence
Swarm-based Algorithms and Behaviors
Construction Assembly Sequence Rules
Swarm Robotics Simulation

- Simulation

After identifying the necessary parameters for the simulation from the Literature review stage, the focus shifts to implementing swarm robots in a dynamic construction site in a virtual simulation environment. This stage involves selecting parameters like the main interface, control algorithm, and assembly-sequence rules, as outlined in the methodology workflow. While the pre- selection of the three mentioned factors is based on background information, personalized experiments are crucial for finding the most compatible options. Compatibility of interface, control algorithms and build-assembly rules depend on factors like the researcher's computational skills, structural knowledge, and accessibility of interfaces and computing engines for simulation.

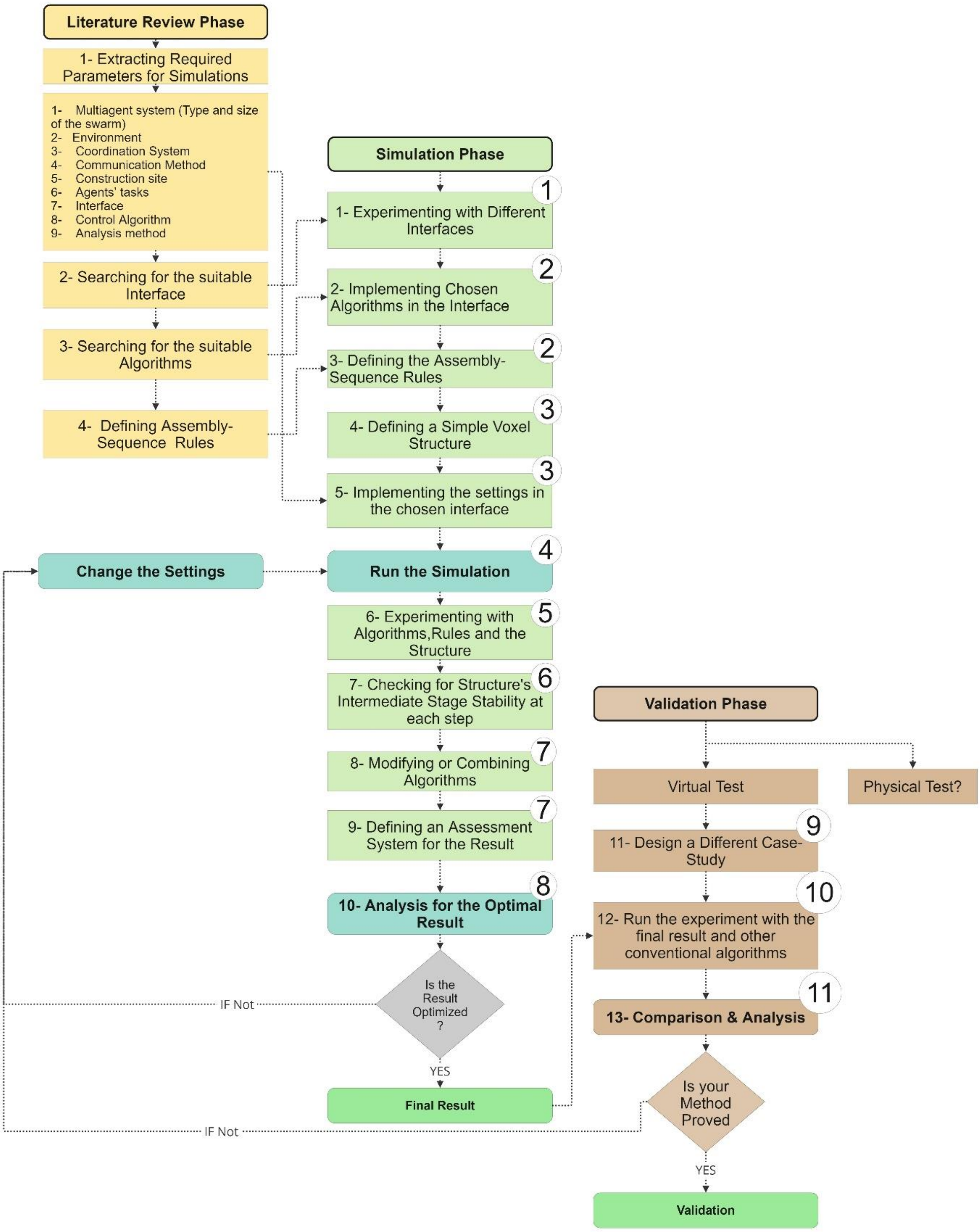
Moving forward, stage three involves designing a low-rise voxel-based structure that best represents the challenges of assembly sequencing. All identified parameters and settings must be incorporated into the interface's settings to prepare for the first simulation run in stage four. During this stage after ensuring the functionality of the simulation, experiments with control algorithms and build-sequence rules begin.

At stage five, Control algorithm studies entail modifying and combining conventional swarm-based algorithms, focusing on path-planning and collision avoidance. In the build-assembly sequence, the focus lies in ensuring the structure's stability throughout the parallel construction process in all intermediate stages, as well as assessing the robots' movement abilities. It is worth mentioning that there might be a bridging structural plugin or algorithm or interface to evaluate the structural stability and enter feedback in the algorithm loop.

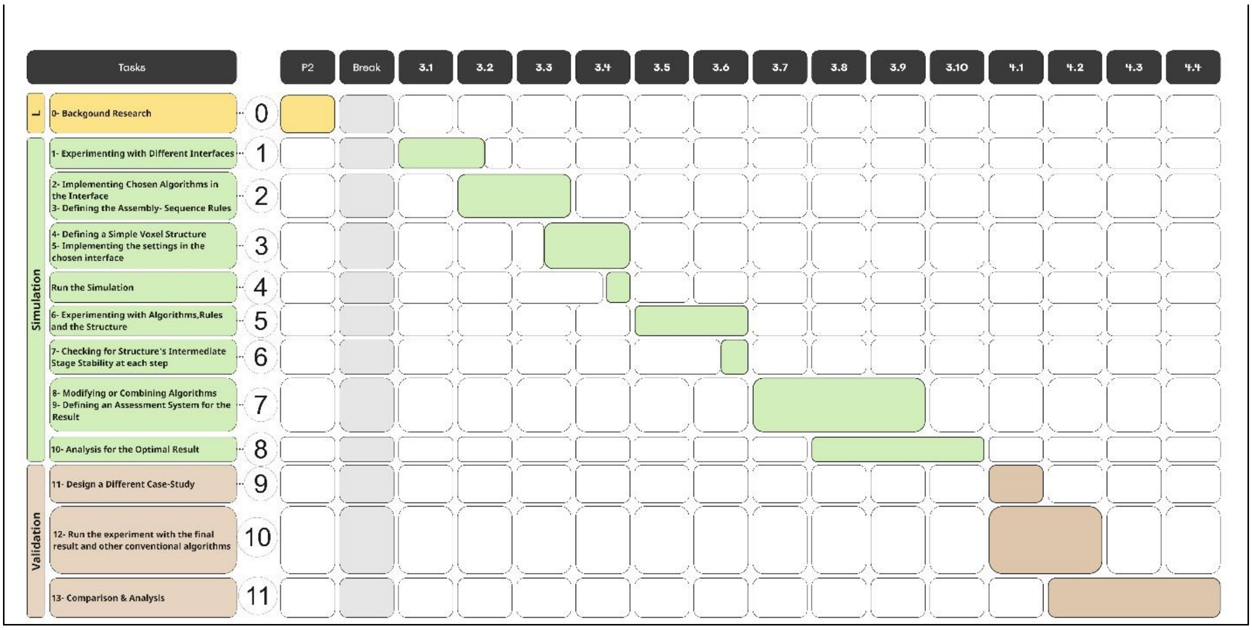
At stage seven, the results of all simulations with modified algorithms and rules are evaluated based on predefined criteria aligned with the simulation's objective. Background information suggests that assessing the performance of swarm robots can be based on factors such as minimizing total distance traveled, maximizing fault tolerance, minimizing total assembly time, or reducing the number of iterations required for the algorithm to complete the structure. This performance objective will be defined in the later steps.
During the analysis stage, if the desired results are not achieved according to the evaluation criteria, adjustments to the settings and simulation running process will be ongoing.

- Validation through designing a Case Study

If the results are optimized, we will proceed to the validation phase. Otherwise, adjustments will be made to the settings, and the simulation will be rerun. Upon achieving the desired final result, a virtual test will be conducted using a newly designed structure as the case study to compare our algorithm's results and experiment settings with conventional ones. If the outcome proves superior, the method is approved and will undergo validation. Otherwise, we must revisit the simulation adjustment step and rerun it accordingly.



This timeline outlines the schedule from the beginning of the simulation stage to the conclusion of the validation stage. In the future, additional techniques such as machine learning can be employed. Alternatively, physical tests involving real swarm robots at the IDE faculty under the supervision of Jordan Boyle may also be conducted.


Tasks
P2
Break
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
3.10
4.1
4.2
4.3
4.4
L
0- Backgound Research
0
Simulation
1- Experimenting with Different Interfaces
1
2- Implementing Chosen Algorithms in the Interface
3- Defining the Assembly- Sequence Rules
2
4- Defining a Simple Voxel Structure
5- Implementing the settings in the chosen interface
3
Run the Simulation
4
6- Experimenting with Algorithms,Rules and the Structure
5
7- Checking for Structure's Intermediate Stage Stability at each step
6
8- Modifying or Combining Algorithms
9- Defining an Assessment System for the Result
7
10- Analysis for the Optimal Result
8
Validation
11- Design a Different Case-Study
9
12- Run the experiment with the final result and other conventional algorithms
10
13- Comparison & Analysis
11

Literature and general practical references

Added to this document is a reference list of sources that have been used for the background information.

Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?
2. What is the relevance of your graduation work in the larger social, professional and scientific framework.
   1. This graduation topic perfectly aligns with the BT master track, combining research on enabling construction autonomy on dynamic building sites through the implementation of Swarm Robotics. This research seamlessly integrates structures with design informatics, leveraging the potential of swarm intelligence and computational skills to optimize the construction assembly sequence.
   2. The relevance of my graduation work in the larger social, professional, and scientific framework is significant. Swarm Robots have the potential to revolutionize the construction industry by enabling autonomy in dynamic construction sites through collective perception. This advancement addresses pressing challenges such as labor shortages, safety risks, and the need for sustainability and efficiency in construction. By harnessing the power of Swarm Robots, construction processes can become more streamlined, cost-effective, and environmentally friendly. Additionally, this research contributes to the advancement of robotics in the construction sector, paving the way for future innovations and improvements in the field.

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