Automated Robotics Agents for Assembly-Aware Design of Shells

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ABSTRACT: Form-finding processes for shell structures generates geometric designs which are potentially structurally stable once fully constructed without external supports. The form-found solutions are provided as is, and for segmented shell structures a suitable assembly sequence is not guaranteed to be locally stable at each stage. Assembly problems have been studied geometrically in the field of shell construction. But, as the use of robotics in construction environments is set to increase over the coming decade, then the application of robotics to construction of shell structures requires the study of assembly sequences and stability when robotic arms are adopted. By applying assembly concepts of Non-Directional Blocking Graphs and robot workspace analysis to results of form-finding in parametric design environments, this work presents early-stage research into augmenting the shell design process with assembly feasibility metrics. A workflow is demonstrated for applying robotic workspace data to shell design and generating an assembly plan, with initial robot planning proposed.

1 INTRODUCTION

Shells are efficient thin-walled structures which lend themselves well to aesthetic designs. A variety of shell modelling techniques which have been implemented as parametric design plugins, including Kangaroo (Piker, 2013). The theory behind the membrane dominated loading mechanism for continuous shell structures is well understood, whilst developments are still being made in segmented shell design. A key aspect to designing realisable segmented structures is the design of joining systems (Bletzinger and Ramm, 2014). Parallel to advances in digital modelling are movements in AEC industries towards digital construction techniques; some such technologies make use of automation in manufacture and assembly, with robotics being gradually pushed as a useful tool in creating the built environment. Whilst some recent work from CREATE Princeton presents solutions to the creation of shells using assembly robotics and adhesives (Parascho et al., 2020), the design of shells focusing on panel interfaces and dry stacking requires further exploration. This work seeks to find how a digitally driven assembly process can be applied to segmented shells, and demonstrates a design methodology focused on the feasible assembly of structures.

2 AN ASSEMBLY AWARE DESIGN METHODOLOGY

Figure 1 shows the steps taken and the flow of design data in the proposed design methodology. Two software frameworks are highlighted as interconnected layers in the design process; parametric design software Grasshopper3D™ for geometric design aspects and the Robotic Operating System (ROS) for robotics-related functions. The methodology takes as input a description of an available robot manipulator to create a dataset describing the potential workspace which the shell must fit into. Also taking an input of desired panel stock thickness, planarized segmented shells are designed through form finding.

Multi-objective genetic algorithms (MOGA) are utilised for the selection of appropriate designs which fit within the workspace requirements. An assembly sequencing technique is implemented and described, which uses panel geometry to generate potential directions of translational freedom for elements of the assembly. The free directions are utilised to drive a graph search of potential assembly sequences to inform potential robot trajectories. Finally, an initial robot picking technique is explained, making further use of panel geometry data from Grasshopper for grasp generation.

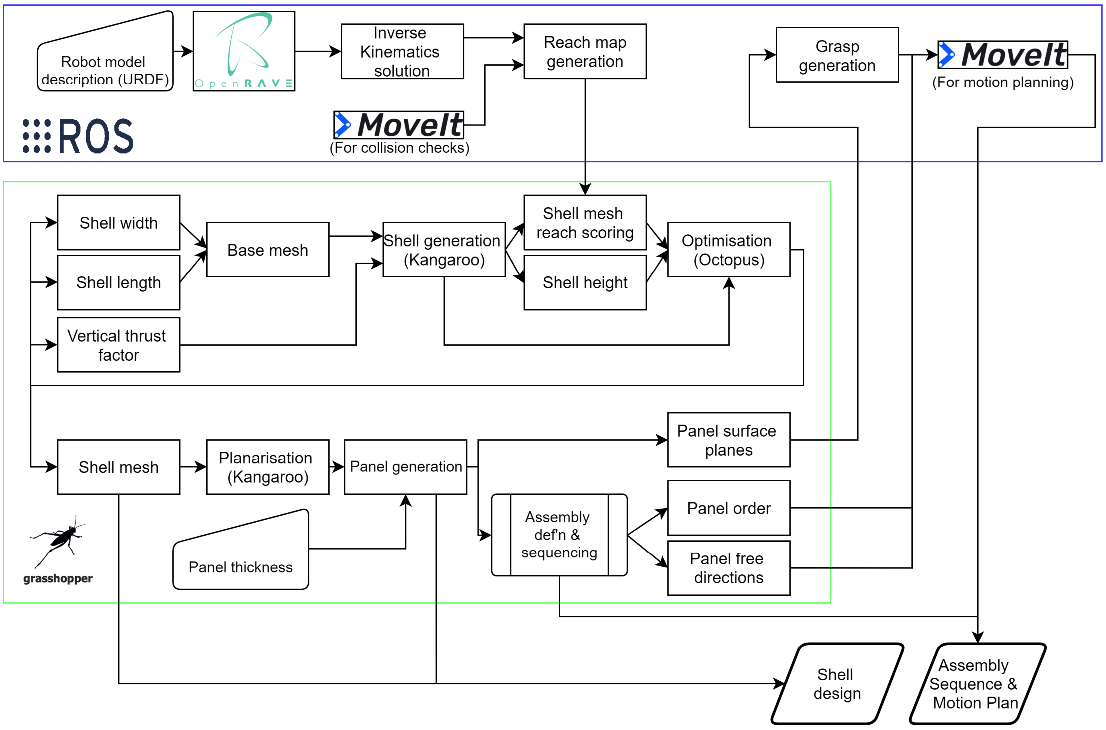

Figure 1. The workflow of the design process.

3 CONCLUSIONS

This paper demonstrates a design methodology which considers the limitations of general-purpose robot arms for shell assembly, to drive design processes based on digital assembly technology. Manipulator reachability analysis is shown as a useful method for storing the kinematic characteristics of robot arms to be used for optimisation of structures. An implementation of assembly sequencing has been described which allows for fast evaluation of shell assemblies to indicate whether a structure is geometrically achievable. Future research will require characterisation of joining methods for panels which are suitable for robot assembly, including structural analysis to develop a system that can remain stable during assembly. A key challenge will be designing to ensure scalability.

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