Abstract

Starting in the 1940s, advances in the chemical industry and composite materials such as Fiber Reinforced Polymers have revolutionized manufacturing enabling new lightweight - high strength applications in the aerospace, automotive, and consumer goods industries. However, composites failed to significantly impact the building industry due to its poor digitalization and low integration of design and engineering methods. Nevertheless, these shortcomings can be mitigated through construction-specific design, fabrication methods, and building regulations for composite structures.
Recent advances in digital design methods in conjunction with newly-available hardware and control systems allow for automated fabrication approaches to re-imagine established fabrication methods such as Filament Winding(FW).

This thesis presents novel upscaling and automation strategies for Coreless Filament Winding(CFW), which is an adaptation of FW to construction applications. CFW is a fabrication method that relies on the anisotropic mechanical properties of free-spanning fibers wound around supports in space to create efficient load bearing structures without requiring molds or dies.

The investigations identified gaps in academic research for construction composites. The thesis demonstrates that existing prefabrication methods of Robotic Coreless Filament Winding (RCFW) can be successfully upscaled and utilized for large-scale, long-span loadbearing structures. Furthermore, the thesis presents an approach to advance existing process-monitoring and quality-control methods, named Cyber-Physical RCFW (CPRCFW). The two objectives are investigated through two representative tasks: (1) verifying the RCFW method's scalability and its industrialization potential, and (2) the development of a CPRCFW method for quality control, integrating winding process automation, process monitoring, data acquisition, and analysis. Each objective is demonstrated through the research and development of hardware, consisting of fabrication setups and tooling and software, comprising CAD-implemented industrial robot motion planning and control algorithms. The objectives are verified through large-scale demonstrators at component and building scale, illustrating how the research findings are conducive to RCFW becoming a valid alternative to industry-verified technologies in composite construction applications.

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