Data science and computational mathematics unite to advance predictive methods in engineering

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The research consortium is developing improved ways of predicting the presence of naturally occurring potentially destructive rogue waves that can have a harmful effect on critical offshore structures. Credit: Ilona Froehlic, Unsplash

A well-known mathematical method, used as a predictive tool in engineering and the physical sciences for more than 70 years, has been radically redesigned in landmark research led by Cambridge engineers.

The Finite Element Method (FEM), a tool that provides computer-simulated solutions to otherwise unsolvable mathematical models, has been at the cornerstone of modern day applied mathematics, numerical analysis and software development, but the ability to integrate data with the FEM to improve techniques for making physical model predictions has been overlooked—until now.

Researchers at the University of Cambridge, the University of Western Australia (UWA) and The Alan Turing Institute have collaborated to redesign the FEM and lay the foundation and methodology by which Digital Twins can be realized. They report their findings in *Proceedings of the National Academy of Sciences* (*PNAS*).

Co-author of the report, Professor Mark Girolami, Sir Kirby Laing Professor of Civil Engineering, Royal Academy of Engineering Research Chair at the University of Cambridge, and Programme Director for Data-Centric Engineering at The Alan Turing Institute, said the research had commercial interest.

"Digital Twins—the pairing of the physical and virtual world—is of significant current interest to the broader engineering community. By integrating data with FEMs, this new work provides the foundation and methodology by which these Digital Twins can be realized," he said.

"By accepting that our mathematical descriptions of complex systems can be wrong and not capture all aspects of the system, we were able to define a statistical description of the FEM that provided a very natural and entirely novel way to blend data and mathematical models in a really powerful way.

"This provides the opportunity to couple statistical techniques with FEMs to lay the mathematical foundations of the Digital Twin revolution. Until now, how data can be taken directly into account has been missing from FEMs."

The PNAS paper demonstrates the method in the context of improving our understanding of oceanic solitons, i.e. large amplitude internal waves that occur on Australia's North West Shelf and elsewhere around the world.

Connor Duffin, Ph.D. student from UWA's School of Physics, Mathematics and Computing and lead author on the paper, added: "Scientifically, solitons are significant events that introduce turbulence and mixing, that impact local fertilization, and hence biology, due to nutrients from the seabed being dispersed into the water column. For engineering practice, predicting the occurrence and magnitude of solitons is of particular interest to the Australian offshore industry, as it impacts the safety and operation of current and future assets."

More information: Connor Duffin et al. Statistical finite elements for misspecified models, *Proceedings of the National Academy of Sciences* (2020). DOI: 10.1073/pnas.2015006118

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