Assessing wind-driven rain loads on traditional buildings using computational fluid dynamics and 3D digital documentation data

Adam Frost[a, b], Scott Allan Orr[a], Josep Grau-Bove[a], Lyn Wilson[b]

[a] UCL Institute for Sustainable Heritage, London, UK
[b] Historic Environment Scotland, Stirling, UK

Abstract

Moisture in building fabric from wind-driven rain (WDR) is associated with several erosion decay mechanisms. To relate the WDR load to known issues from moisture in traditional buildings, several methods can be used to calculate WDR loads on building facades. Computational Fluid Dynamics (CFD) enables detailed modelling of WDR for buildings by simulating coupled wind flow and rainfall, but implementations for traditional buildings often use simplified hard surface modelling of architectural details. We apply the open source OpenFOAM windDrivenRainFoam solver to 3D digital documentation survey data for Melrose Abbey, Scotland. This approach enables detailed representation of building geometry with flexibility to change resolution as required, based on an accurate high resolution geometric dataset.

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Keywords: WDR; CFD; precipitation; porous masonry; climate change; rainfall; traditional buildings; built heritage

1. Introduction

Wind-driven rain (WDR) is a significant source of moisture in the traditional built environment, with links to building hygrothermal performance and key decay mechanisms that affect building masonry, such as freeze-thaw, salt crystallisation and biological growth [1]. Previous work to model the impact of WDR on buildings includes the use of Computational Fluid Dynamics (CFD), simulating wind and rain as one-way coupled fluid phases [2, 3]. WDR CFD analysis typically requires a representation of the building as 3D geometry, often this is a relatively simplified massing model developed through hard surface modelling [4, 5].

This work aims to establish a workflow for using high resolution 3D digital documentation data for detailed WDR CFD analysis, by applying the open-source OpenFOAM windDrivenRainFoam (WDRF) [4] solver to the case study site of Melrose Abbey, a Historic Environment Scotland (HES) property-in-care located in the Scottish borders. With UK climate projections showing trends towards more intense rainfall over the next 20 years [6], it is essential to understand the WDR loads on masonry for long-term hazard assessment. The modelled precipitation for Melrose shows the wettest month is January with 19.5 days of rain, with the most intense rainfall occurring in July and August (0.5 days > 20 mm hr^{-1} respectively).

2. Methodology

2.1. 3D digital documentation

The simulation geometry was derived from a 3D laser scanning and photogrammetry dataset. The dataset was created in 2017/8 as part of the HES Rae Project [8]. The survey specification defined 5-10mm surface resolution using terrestrial laser scanning registered to a control network, with additional photogrammetric images captured via UAV. Alignment and data fusion between the TLS and photogrammetry datasets was undertaken using RealityCapture. The full resolution 3D model was reduced using RealityCapture's simplification algorithm. Landscape and upstream geometry is omitted from this simulation, though its importance for accurate wind flow field data is recognized for future work.

2.2. Domain configuration, mesh and solvers

The alignment of the domain inlet and outlet with the building geometry was SW-NE, to simulate the wind phase as prevailing south westerly based on averaged weather data [7]. Computational domain and geometry setup was designed in the open-source 3D modelling package Blender, with the SnappyHexMesh Blender GUI add-on [9]. SnappyHexMesh was used

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to generate the mesh, with cell-length set to 5.0 and surface refinement levels set to min 1, max 5. The WDRF solver resources and guidelines [10] were used for the WDR simulations. The domain inlet boundary condition was configured with the atmospheric boundary layer profile and a reference wind-speed of 10m/s. The wind phase was simulated using SimpleFoam, an incompressible steady-state RANS solver packaged with OpenFOAM (v9). The rain phase was subsequently solved using the WDRF solver, coupled (one way) using the wind field data.

3. Results and discussions

The results of the wind-driven rain simulation are visualised as catch ratio on the geometry surface, Figure 1. Global catch ratio (GCR) is expressed for 6 discrete different rainfall intensities (0.1; 1; 2.5; 5; 10; 30mm hr^{-1}), based on probability distribution for different raindrop sizes.

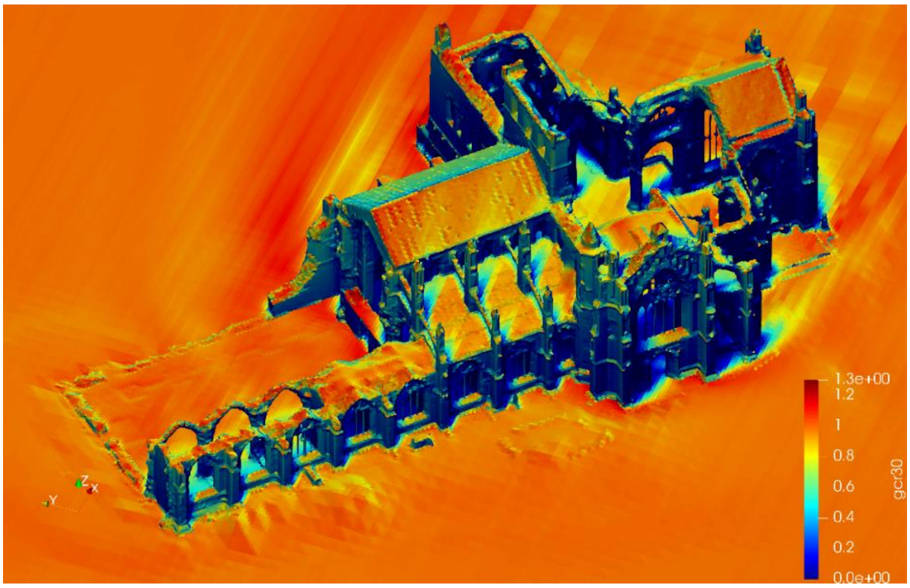

Figure 1. Oblique orthographic view of Melrose Abbey from SSW, showing global catch ratio at 30mm hr^{-1} intensity.

The resolution and accuracy of the mesh enables detailed inspection of the catch ratio across the building geometry, including architectural details such as flying buttresses, finials and roof elements that are exposed to higher levels of wind-driven rain and may occlude other areas of building fabric. Importantly, the condition of the building is reflected in the geometry, such as where original built elements are missing or have been consolidated through conservation practice over time. 3D digital documentation-to-mesh workflows enable the CFD mesh to be generated at different levels of detail as required to resolve finer WDR interactions. This workflow will aid research linked to the ongoing inspection of building fabric across the HES estate, supporting high-level masonry assessment and condition survey.

References

[1] Sesana, E., Gagnon, A. S., Ciantelli, C., Cassar, J.; & Hughes, J. J. (2021). Climate change impacts on cultural heritage: A literature review. WIREs Climate Change, 12(4). doi:10.1002/wcc.710
[2] Choi, E. (1993). Simulation of wind-driven-rain around a building. Journal of Wind Engineering and Industrial Aerodynamics, 46-47, 721-729. doi:10.1016/0167-6105(93)90342-l
[3] Blocken, B. & Carmeliet, J. (2007). Validation of CFD simulations of wind-driven rain on a low-rise building facade. Building and Environment, 42(7), 2530-2548. doi:10.1016/j.buildenv.2006.07.032
[4] Kubilay, A., Derome, D., Blocken, B.; & Carmeliet, J. (2013). CFD simulation and validation of wind-driven rain on a building facade with an Eulerian multiphase model. Building and Environment, 61, 69-81. doi:10.1016/j.buildenv.2012.12.005
[5] Bourcet, J., Kubilay, A., Derome, D.; & Carmeliet, J. (2021). Impact of climate change on the wind-driven rain exposure of a historical building. Journal of Physics: Conference Series, 2069(1), 012054. doi:10.1088/1742-6596/2069/1/012054
[6] Met Office Hadley Centre (2019) UK Climate Projections: Headline Findings. Available online: <https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp-headline-findings-v2.pdf> Last accessed: 2021-05-21
[7] Simulated historical climate & weather data for Melrose - meteoblue. (2022). Retrieved December 8, 2022, from https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/melrose_united-kingdom_2642769
[8] Digital Documentation team: Engine Shed: Scotland's Building Conservation Centre. (2022). Retrieved December 8, 2022, from https://www.engineshed.scot/about-us/teams/digital-documentation-and-digital-innovation/the-rae-project/
[9] Tkeskita. (2022). Tkeskita/SNAPPYHEXMESH_GUI: Snappyhexmesh Gui addon for Blender. Retrieved December 8, 2022, from https://github.com/tkeskita/snappyhexmesh_gui
[10] ETH Zurich Chair of Building Physics (2022) Retrieved December 8, 2022, from https://gitlab.ethz.ch/openfoam-cbp/solvers/winddrivenrainfoam