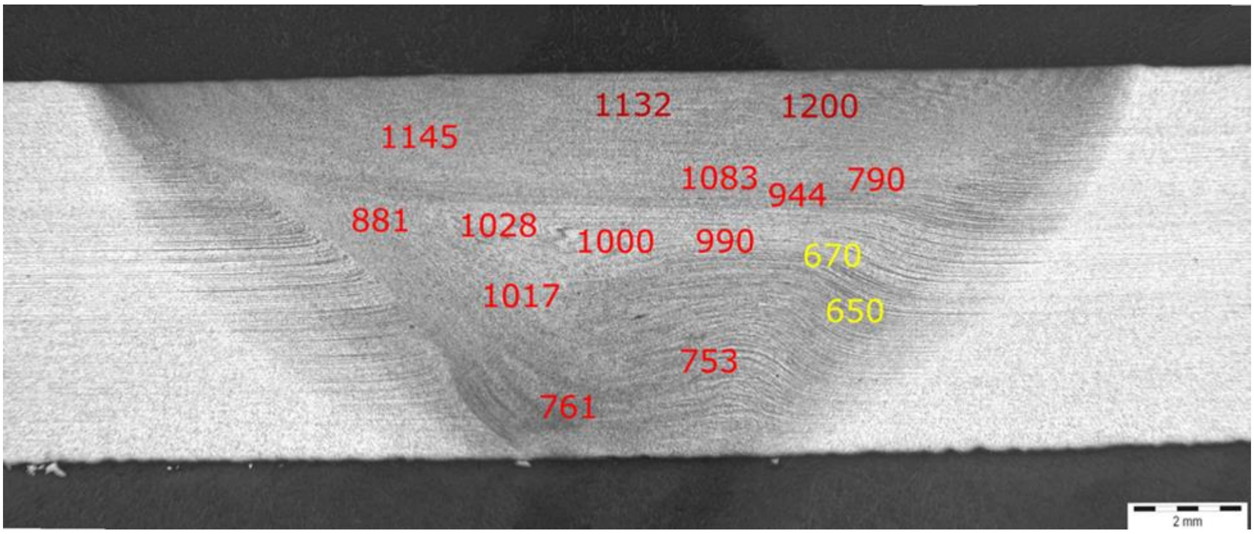


Figure 1. Temperatures measured inside the FSW zone of 6 mm thick DH36 steel plate welded at 400 mm/min traverse speed, 550 rpm rotation speed (weld advancing side on the left)

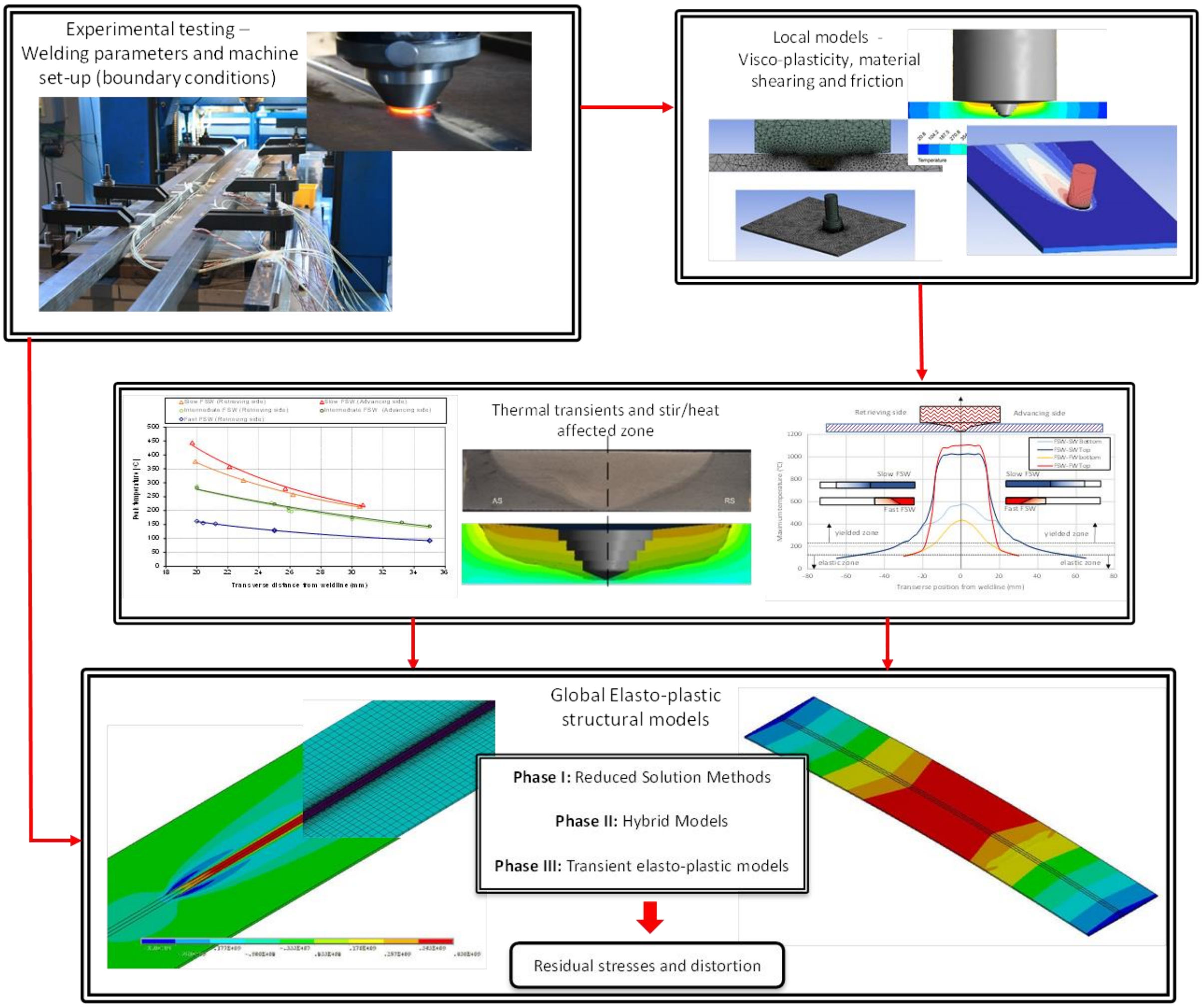
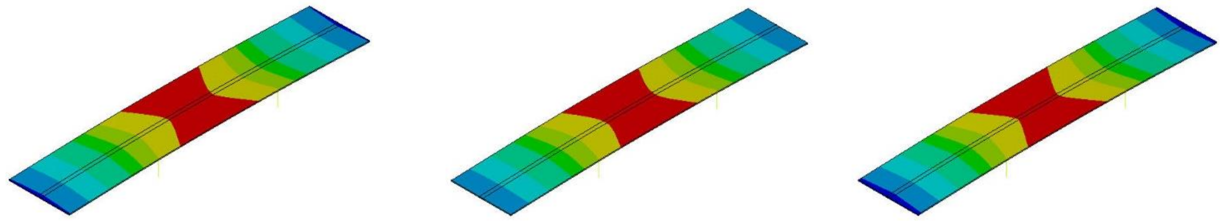
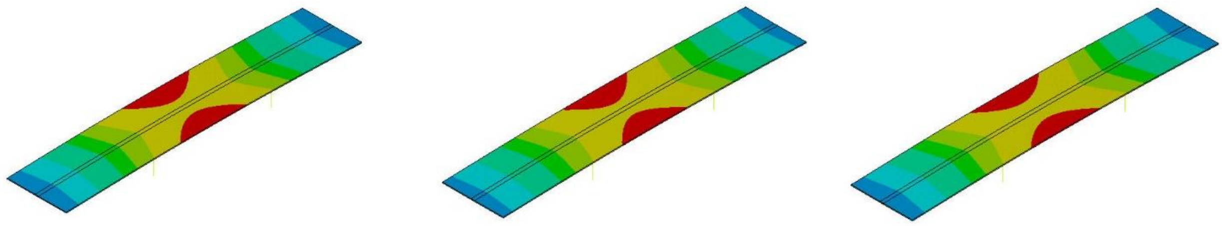


Figure 2. Numerical modelling strategy and integration between local and global models



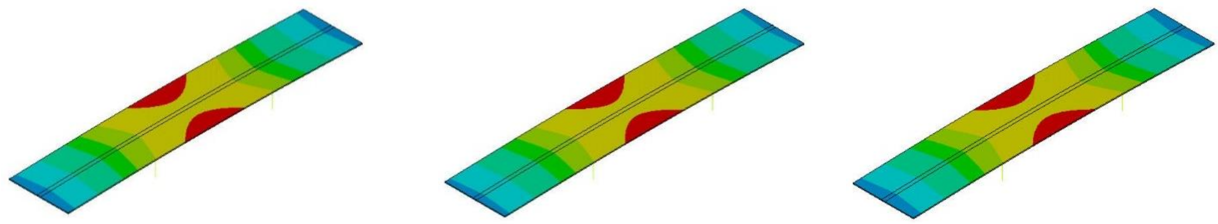
i) Calibrated heat loss I (CS) ii) Low heat loss (LS) iii) High heat loss (HS)

a) Slow welds: 200 rpm – 175 mm/min



i) Calibrated heat loss II (CI) ii) Low heat loss (LI) iii) High heat loss (HI)

b) Intermediate welds: 400 rpm – 325 mm/min



i) Calibrated heat loss II (CI) ii) Low heat loss (LI) iii) High heat loss (HI)

c) Fast welds: 700 rpm – 500 mm/min

Figure 3. Predicted out-of-plane distortion for different welding parameters and heat loss parameters – Plate C 2 m x 0.4 m

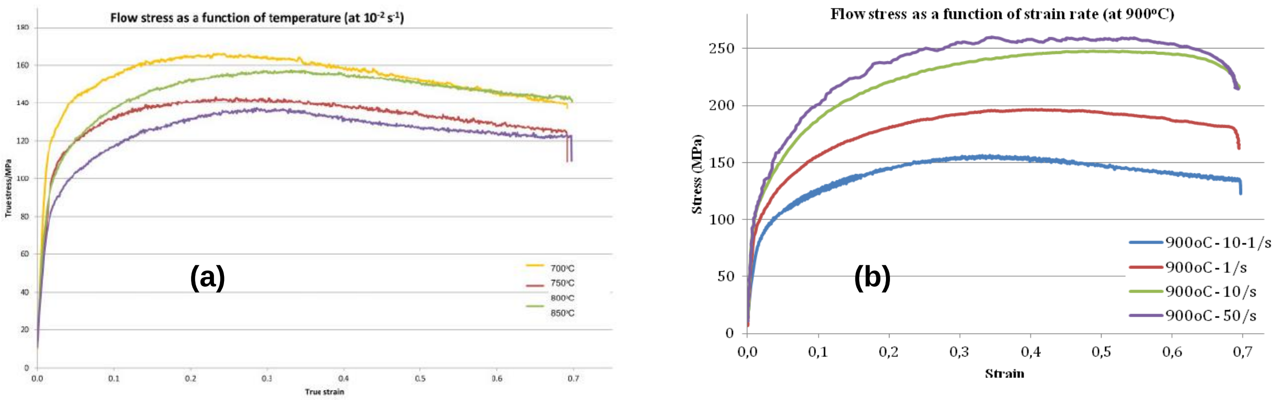


Figure 4. Flow stress at (a) fixed strain rate & (b) fixed temperature

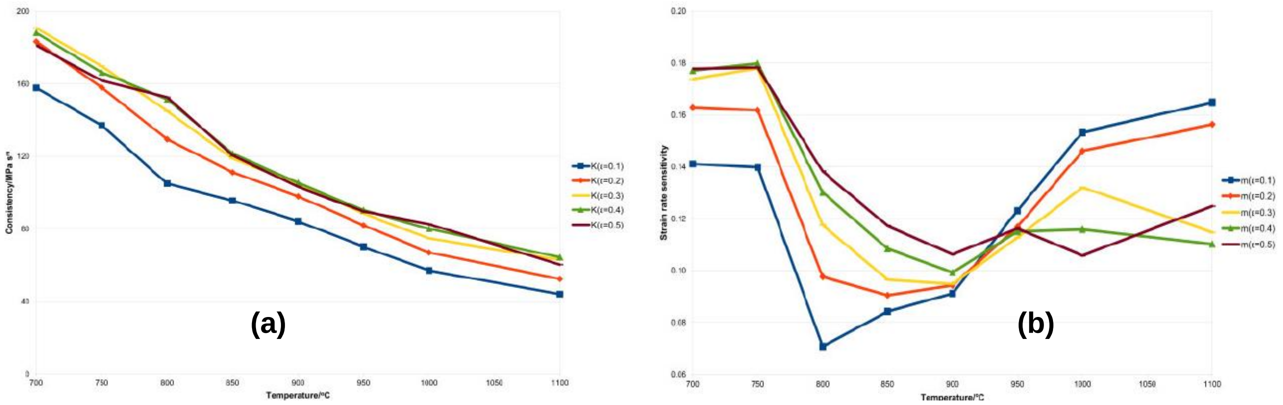


Figure 5. Evolution of material properties with temperature; (a) consistency, (b) strain rate sensitivity

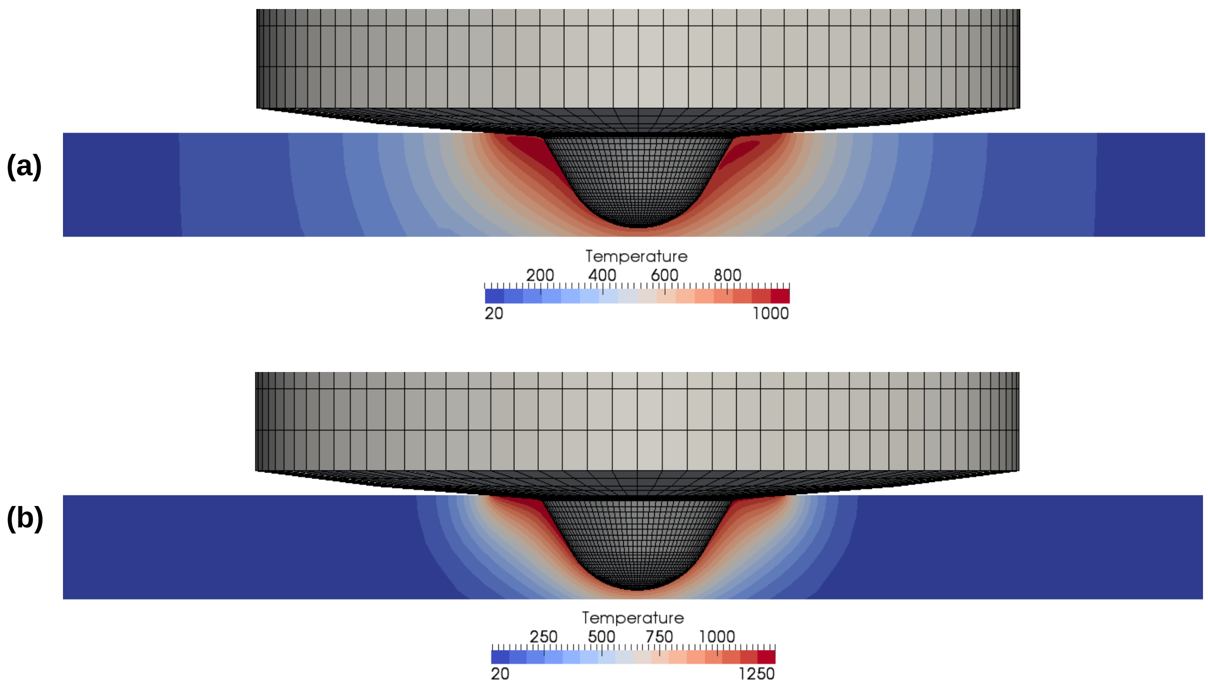


Figure 6. Temperature distribution in a transverse section of weld material around the tool; (a) 200 rpm – 100 mm/min, (b) 500 rpm – 400 mm/min

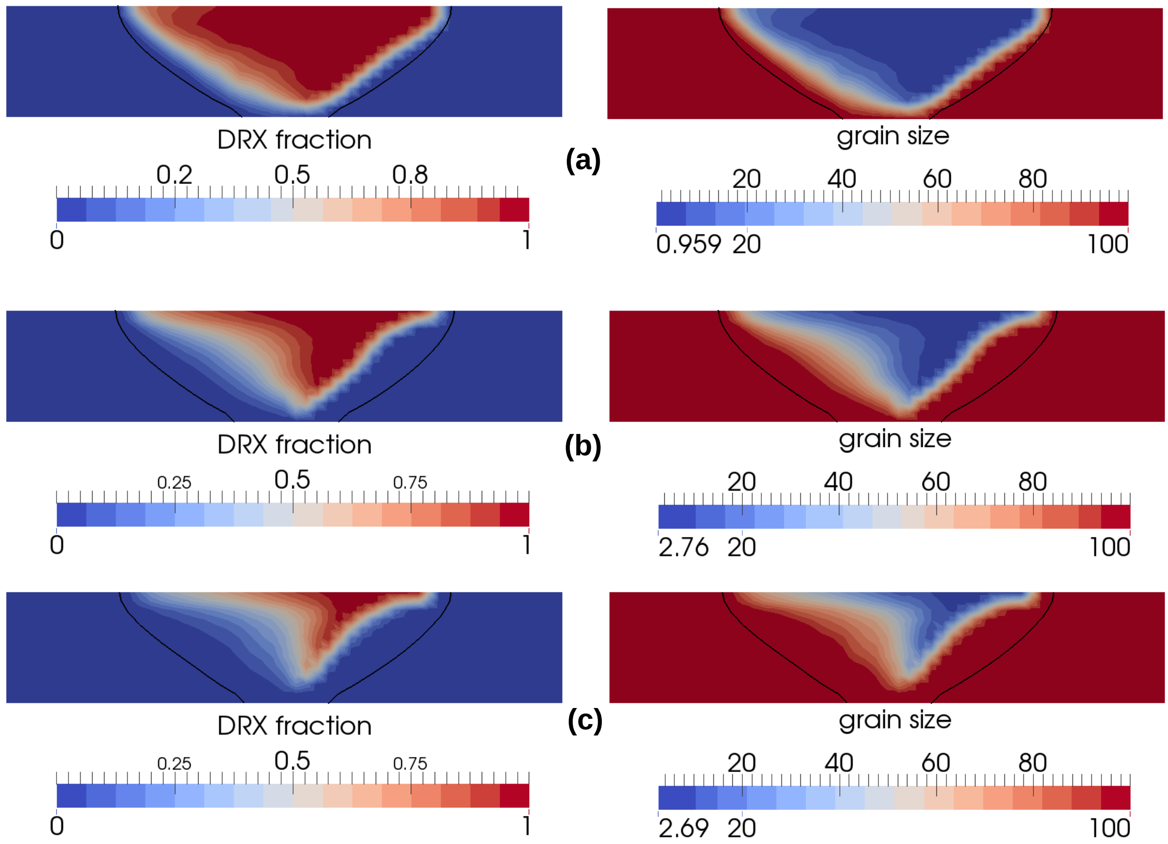


Figure 7. Recrystallized fraction and grain size in the weld zone for (a) slow, (b) intermediate & (c) fast FSW group

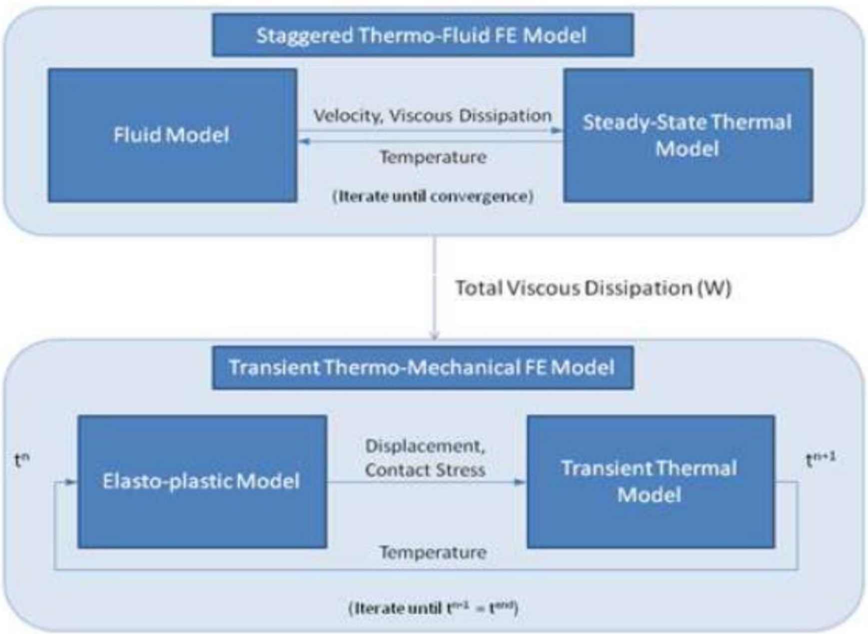


Figure 8. Overview of the coupling between the local and global analyses

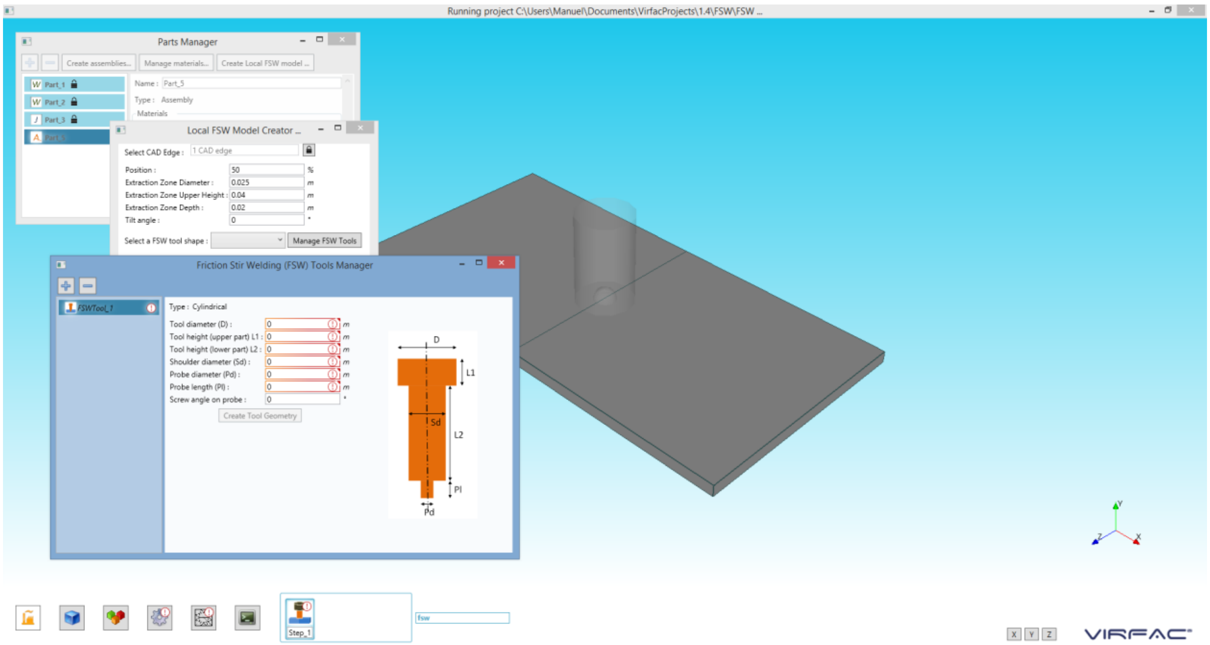


Figure 9. FSW tool definition

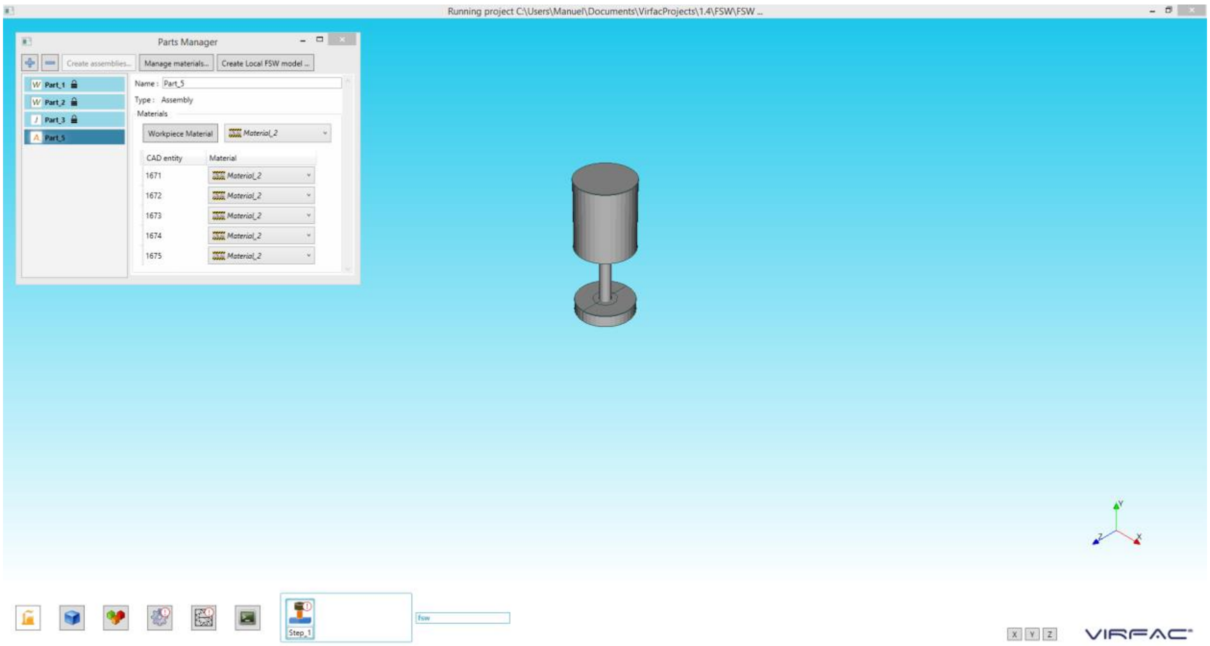


Figure 10. Local model extraction

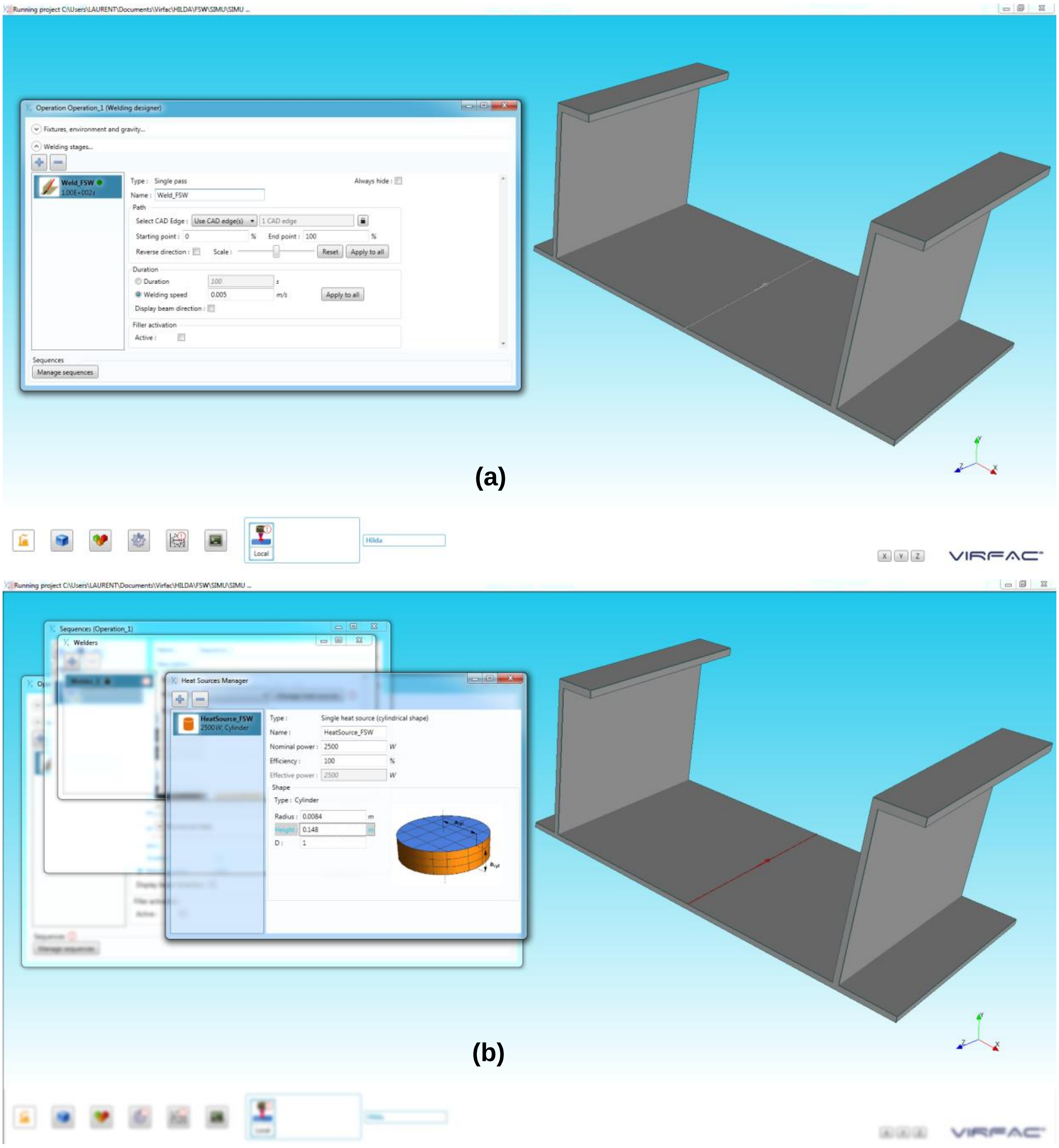


Figure 11. Definition of welding process parameters (a) trajectory, welding speed (b) heat source

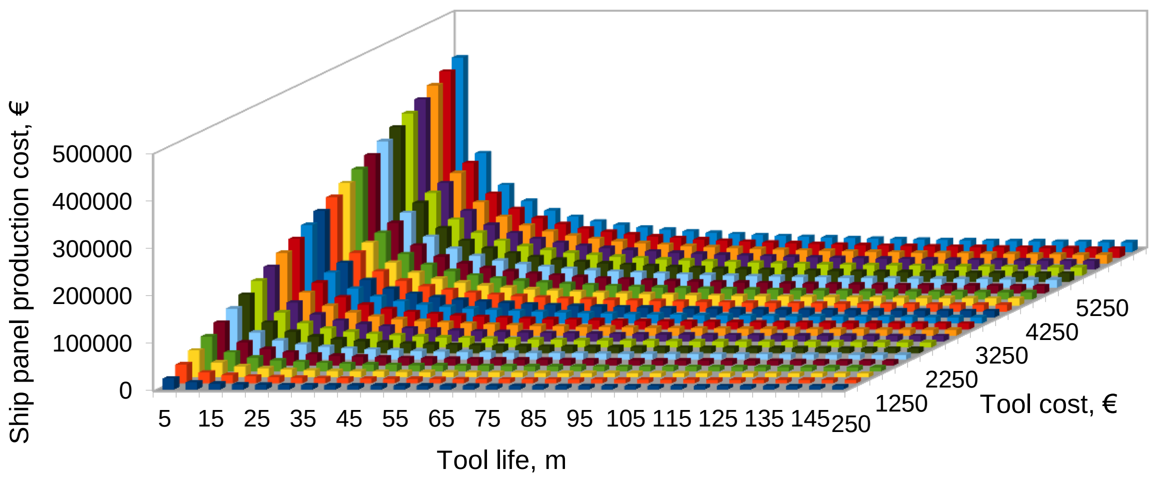


Figure 12. Sensitivity response surface

Table 1. FSW potential economic benefit foundations

Potential benefit of FSW	Social benefit	Economic benefit	Economic value
Elimination of molten metal injury	√	√	• No requirement for protective clothing, gauntlets, goggles. Potential saving of €390 per welder per year. • Reduction in death / sickness related costs.
Elimination of UV exposure	√	√	• No costs for goggles or welding screens. Potential saving of €160 per welder per year. • Reduction in injury costs; $467 million per year in the USA (no comparable figure for EU).
Elimination of fume exposure	√	√	• No requirement for breathing masks or fume extraction systems. Potential saving of €12,000 per year based on small to medium sized yard. • Reduction in injury costs.
Reduction of vibration induced injury	√	√	• Reduction in injury related costs.
Enhanced weld strength		√	• Increased safety factors.
Enhanced fatigue performance		√	• Increased vessel service life. • Reduction in other fatigue mitigation measures.
Enhanced corrosion performance		√	• Increased vessel service life. • Reduction in corrosion mitigation measures.
Enhanced weld toughness		√	• Increased safety factors.
Ability to weld high alloy and complex steels		√	• Reduction in welding cost.
Ability to make dissimilar steel joints		√	• Reduction in welding and material costs through elimination of interlayer fabrication techniques.
Reduced training & welder certification costs		√	• Potential reduction of €750 per welder per year based on typical qualification / recertification for arc welding.