CMBBE International Symposium on Computer Methods in Biomechanics and Biomedical Engineering

OPTIMIZATION OF EXTRUSION-BASED BIOPRINTING PARAMETERS USING CFD SIMULATIONS AND DOE

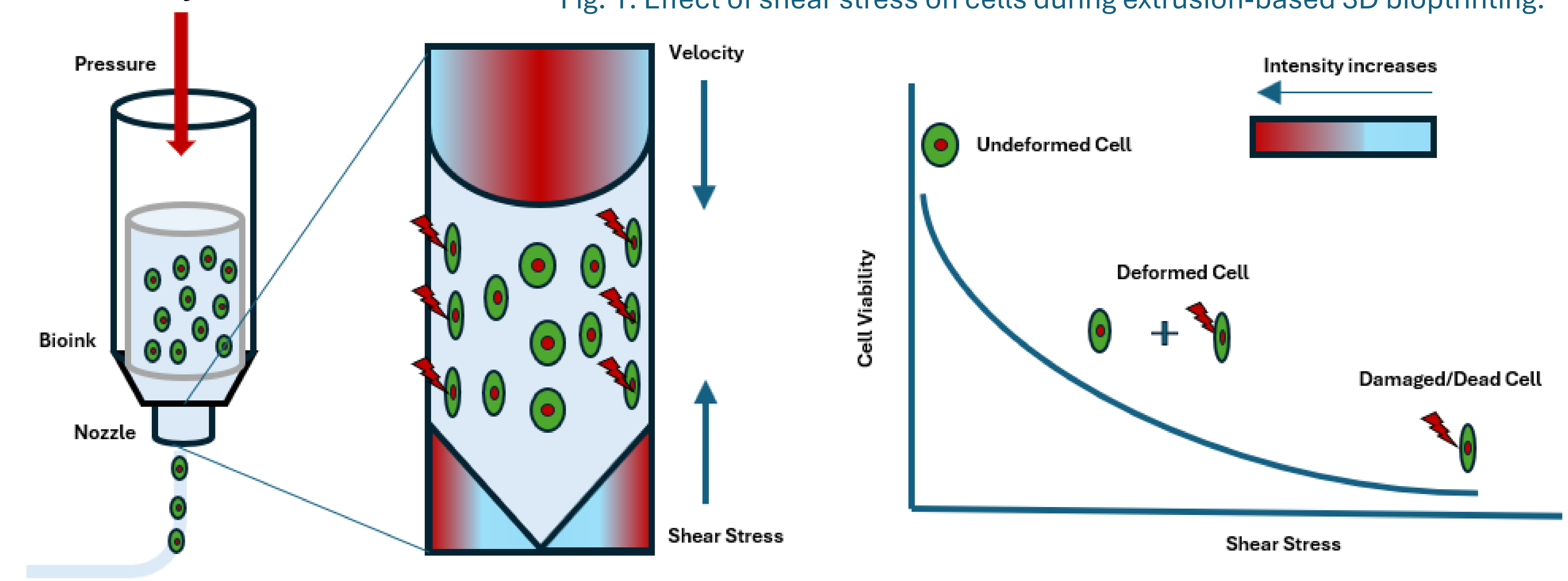
Maria Basañez (1), Juan Manuel Rodriguez (2), Anisabel Valdez (2), Pedro Guerrero (3)

1. Digital Health and Biomedical Applications Area, Vicomtech Foundation, Basque Research and Technology Alliance (BRTA), Donostia-San Sebastián, Spain; 2. School of Applied Sciences and Engineering, EAFIT University, Medellín, Colombia; 3. BIOMAT Research Group, Escuela de Ingeniería de Gipuzkoa, University of the Basque Country, Donostia-San Sebastián, Spain .

INTRODUCTION

Extrusion-based bioprinting is widely used, but **excessive shear stress can compromise cell viability [1].**

Fig. 1: Effect of shear stress on cells during extrusión-based 3D bioptrinting.



This study combines CFD simulations and rheological experiments to evaluate the effect of nozzle geometry, material viscosity, and extrusion parameters on shear stress and pressure drop.

METHODOLOGY

CFD Simulations: ANSYS Fluent, 2D axisymmetric.
Nozzle types: Conical and cylindrical; outlet diameters (OD): 0.26 to 0.6 mm.

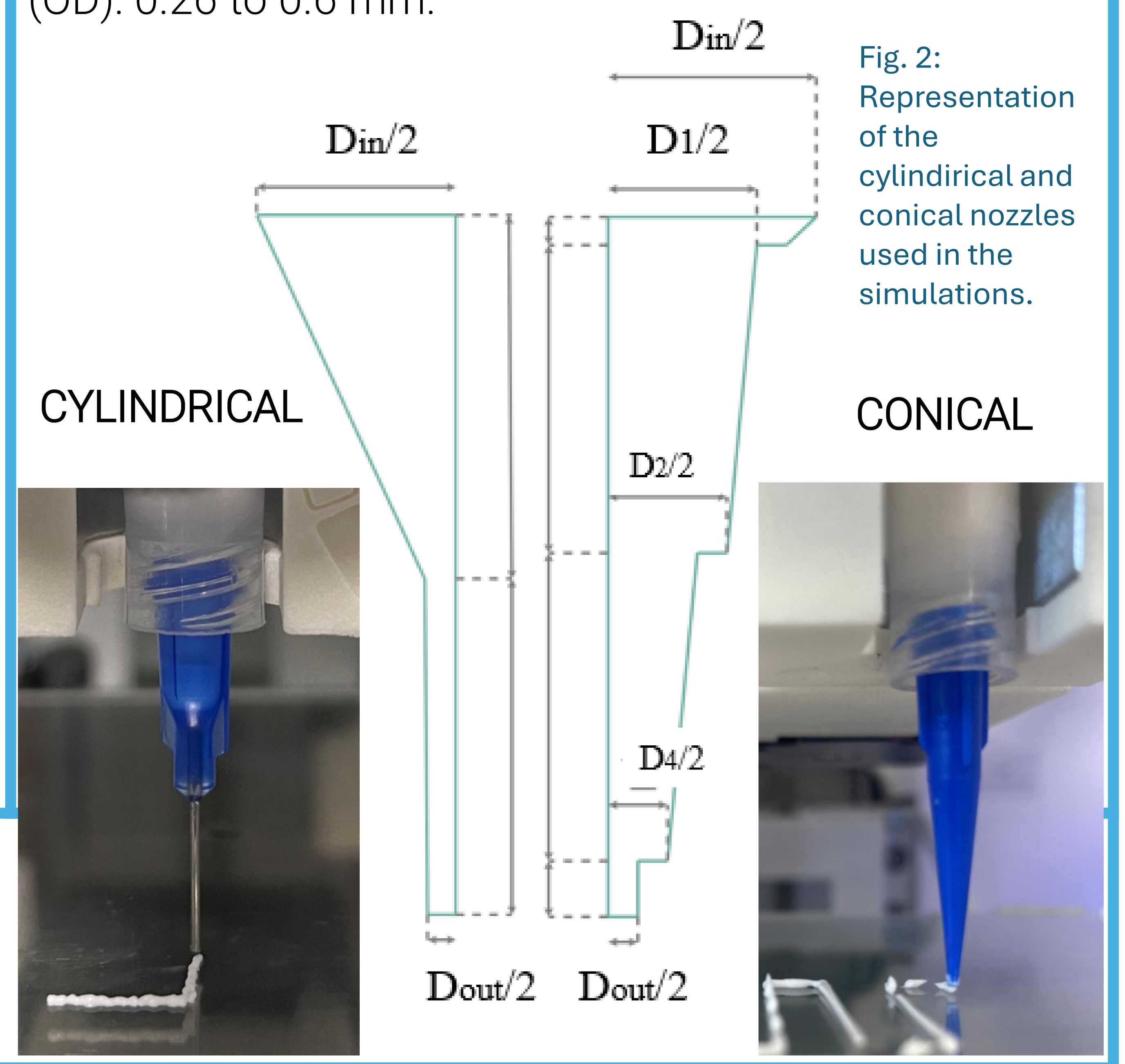


Fig. 2: Representation of the cylindrical and conical nozzles used in the simulations.

Bioinks: Shear-thinning materials (viscosities: 280-64,000 Pa·s), Carreau-Yasuda model.
Experimental Design: Full factorial DoE → nozzle geometry, OD, piston velocity, viscosity.
Statistical Analysis: ANOVA to assess impacts on shear stress and pressure drop.
Predictive Model: Developed to estimate shear stress under varying printing conditions.

RESULTS AND DISCUSSION

Bioink viscosity dominates stress levels. Vaseline is "unsafe" for bioprinting in narrow cylindrical nozzles; nanocellulose is the most biocompatible option.

Material	Conical Nozzle	Cylindrical Nozzle
Nanocellulose	Low (200–2000 Pa)	Low–Medium (400–2400 Pa)
Nivea	Medium (~1800 Pa, stable)	Medium–High (3,000–15,000 Pa)
Vaseline	High (2,500–22,000 Pa)	Extreme (30,000–680,000 Pa)

Conical nozzles strongly mitigate shear stress across all materials, provides more stable extrusion → best choice for cell viability.

Outlet diameter is critical: smaller diameters drastically increase stress in cylindrical nozzles, but effect is mild in conical nozzles. Input velocity is secondary → negligible in conical, geometry but amplifies stress in cylindrical nozzles.

CONICAL NOZZLE

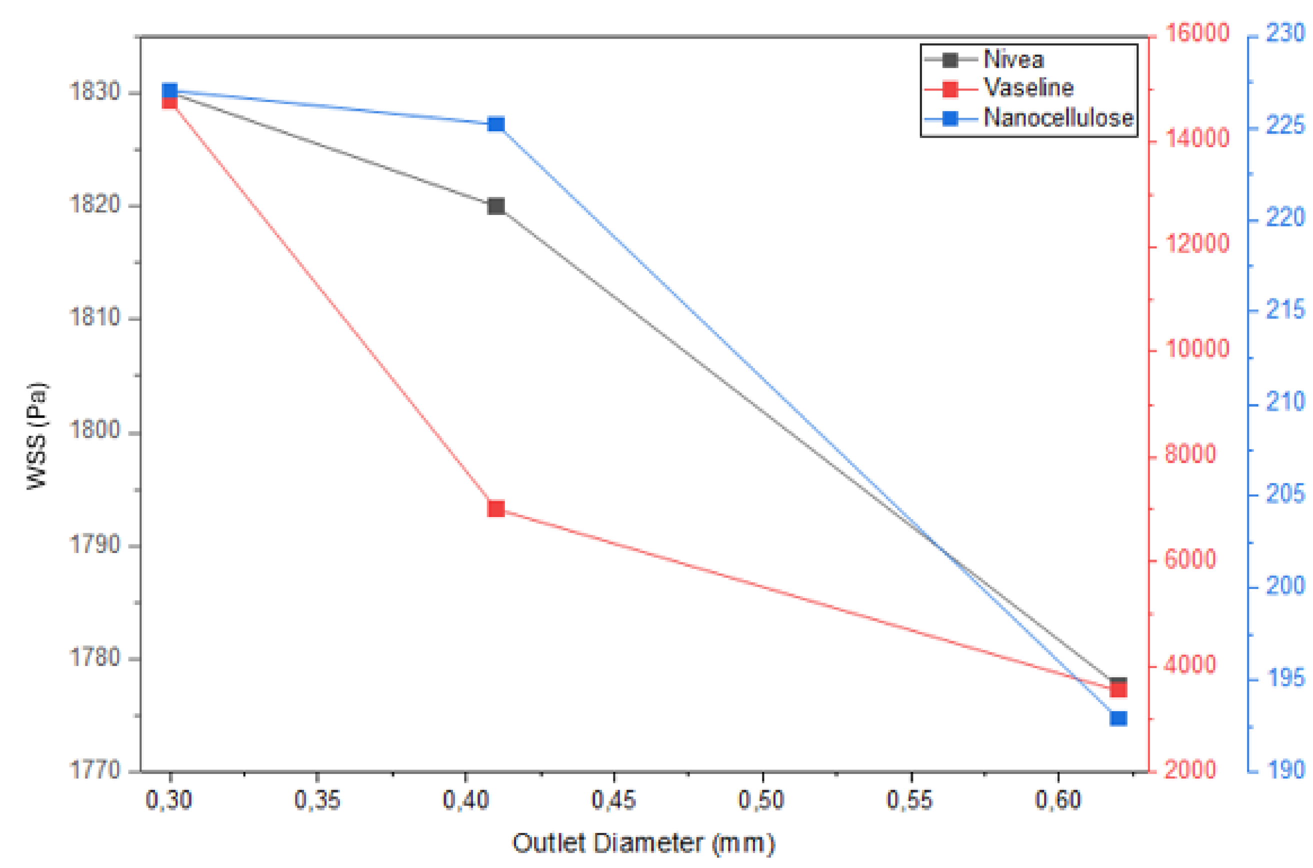


Fig. 3: WSS for varying outlet diameter in conical nozzles, for the three investigated materials.

Relevance of variables on WSS

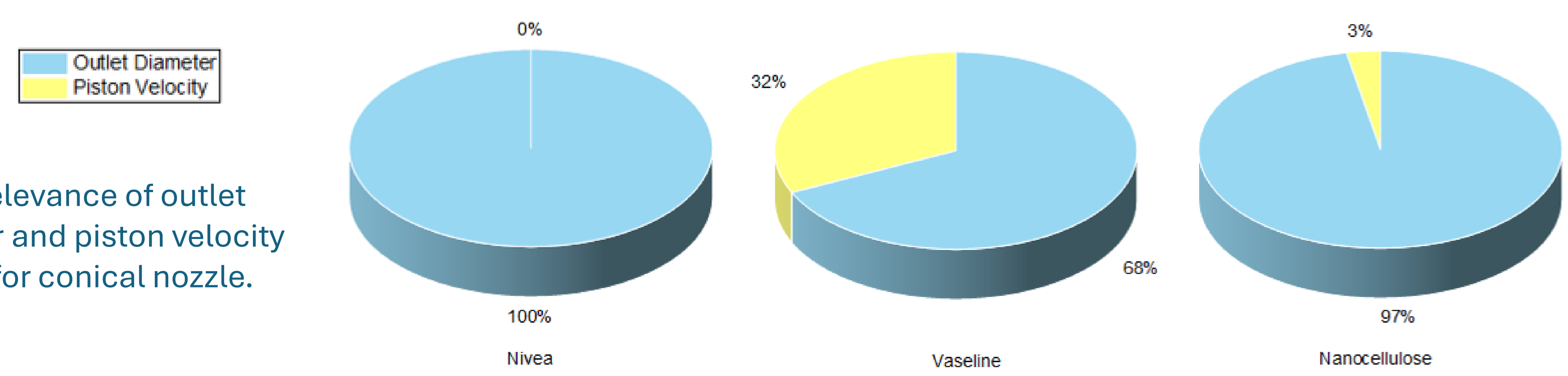


Fig. 4: Relevance of outlet diameter and piston velocity on WSS for conical nozzle.

$Nanocell : \frac{\tau}{\frac{\mu V}{D}} = f(Re, \frac{D}{D_{in}})$

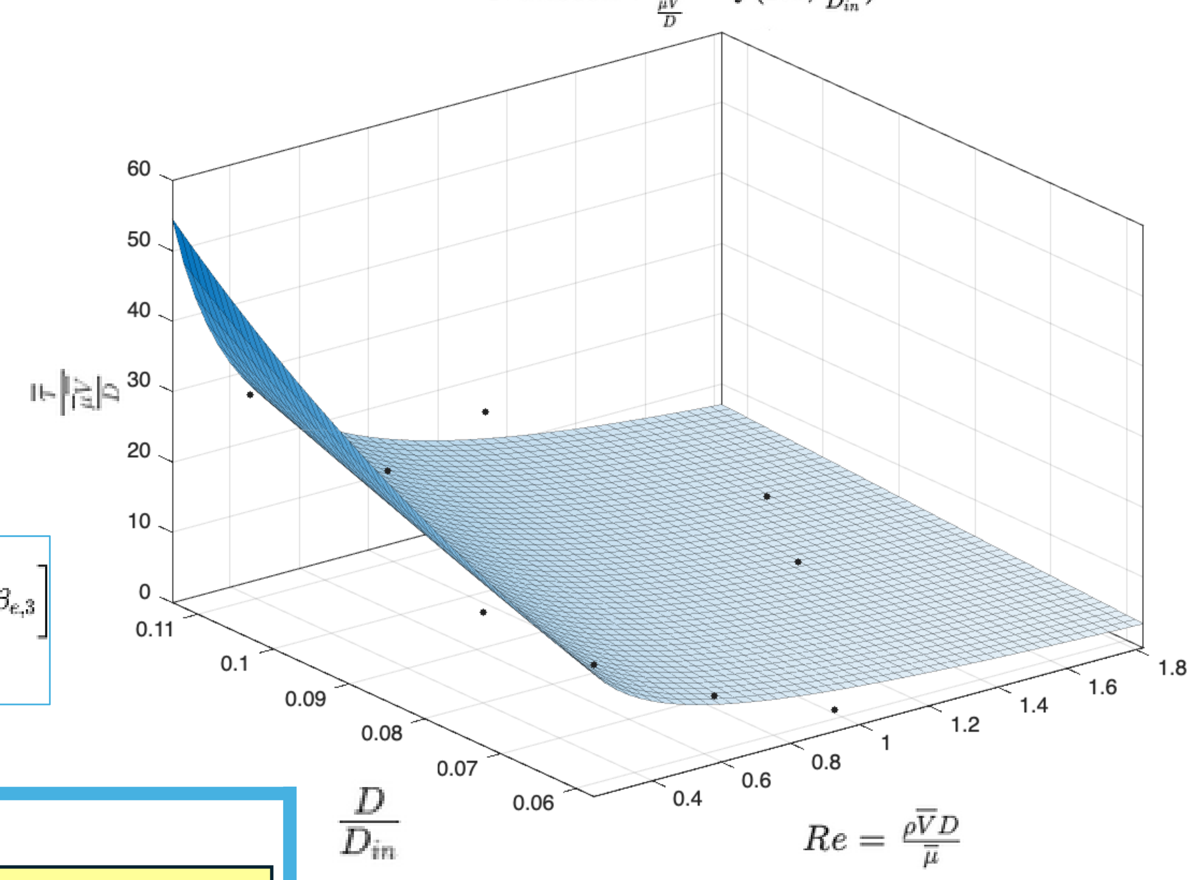


Fig. 5: Surface plot of the predictive model with the simulation data for nanocellulose.

Predictive model: Provide a fast, practical tool to reliably estimate WSS, saving experimental and compuataional effort.
→ Power-law Reducted-Order Model calibrated on CFD data

$$\tau_e^n = \left[\alpha_{e,1}\left(\frac{D}{D_{in}}\right)^{\alpha_{e,2}} + \alpha_{e,3}\right](Re)^{-\left[\beta_{e,1}\left(\frac{D}{D_{in}}\right)^{\beta_{e,2}}+\beta_{e,3}\right]}$$

CONCLUSIONS

Conical nozzles and larger outlet diameters provide the most favorable printing conditions, particularly for high-viscosity inks, whereas cylindrical nozzles with small diameters and high velocities induce critical shear stresses that can compromise cell viability.

Future Directions:
Biological validation: experiments with living cells to confirm correlation between simulated stress and cell viability.
Predictive model refinement: expand training dataset with more CFD simulations → reduce error and improve robustness.
User-friendly tool: integrate the model into a calculator or software plugin to guide parameter selection in real-time

REFERENCES

[1] Boularaoui, S., Al Hussein, G., Khan, K. A., Christoforou, N., & Stefanini, C. (2020). An overview of extrusion-based bioprinting with a focus on induced shear stress and its effect on cell viability. Bioprinting, 20. https://doi.org/10.1016/j.bprint.2020.e00093
[2] Chirianni, F., Vairo, G., & Marino, M. (2024). Development of process design tools for extrusion-based bioprinting: From numerical simulations to nomograms through reduced-order modeling. Computer Methods in Applied Mechanics and Engineering, 419, 116685. https://doi.org/10.1016/j.cma.2023.116685

mbasanez@vicomtech.org

Funded by the European Union