Contribution to the development of a digital twin for the construction field by FAM 3D printing

Élodie PAQUET, Phillipe POULLAIN, Benoit FURET, Sébastien GARNIER, Sébastien LE LOCH

UNIVERSITÉ DE NANTES · LS2N LABORATOIRE DES SCIENCES DU NUMÉRIQUE DE NANTES · IUT NANTES Université de Nantes

CNRIUT'2021 Congrès National de la Recherche des IUT 3 & 4 juin 2021 Lyon

Abstract

This poster deals our contribution to the development of a digital twin based on genetic algorithms that allows us to functionalize the walls of a 3D printed house by taking into account the specificities of the geometry of the house and its orientation of implantations. In the innovative context of digital twins, models were created in order to better control and improve the thermal performance of the house by starting from the insulating functionality of the foam used for their manufacture with the constructive principle "Batiprint3D tm". The results obtained for the Yhnova dwelling, the first social housing manufactured using 3D printing in Nantes in 2017, make it possible to consider enriching the proposed approach by taking into account non-geometric constraints in order to optimize the thickness of the insulating parts of the manufactured walls.

Case study

The Batiprint 3D^{TM} technology [Furet, 2019] which consists of using an expanding foam formwork created by 3D printing can be related to formwork which are formwork elements made with traditional techniques in the construction field. Using printed ICFs shows that the cost of printing the formwork for a house with a method such as Batiprint 3DTm would be 8% cheaper than through traditional wood construction methods and 31% cheaper than traditional ICF construction [Keating, 2017]. This Batiprint 3D ^{Tm} technology was implemented in September 2017 to produce the first 95²m social housing titled YHNOVA certified and printed in France in just 52h.In our case, the creation of a digital twin of the YHNOVA house, allows us to simulate the different scenarios of house implementations with different wall thicknesses depending on the geographical location without increasing the construction costs. The use of a numerical twin allows us to consider different possible functionalizations of the walls, we can mention three main categories: The insulating power of the wall. Ease of installation of the second work and allow customization and architectural freedom.

FIGURE 1: Yhnova digital model on the left and the printed house on the right

Foam Additive Manufacturing process

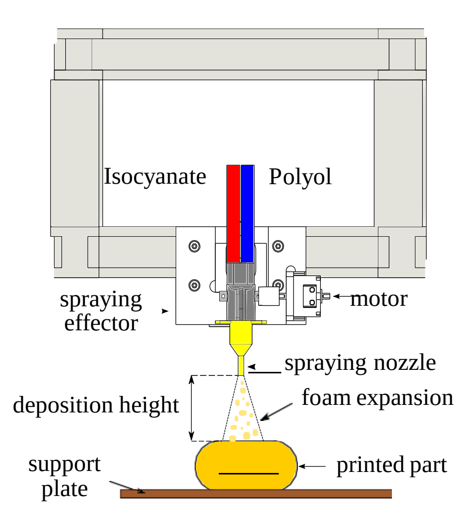

FIGURE 2: Spraying effector

Polyurethane foam is obtained by mixing *Isocyanate* and *Polyol* in a spraying nozzle. The tanks containing separated materials are pressurised which ensure the spraying when the motor actuates the spraying effector. The resulting mixture is sprayed on the part and then expands and solidifies when in contact with ambient air. The foam is deposited layer by layer to form a three-dimensional object. This technology is close to the Foam Deposition Method (FDM) technique, the main difference lies in the nature of the material used, which expands from thirty to forty times its volume in a few seconds. As a result, this foam leads to large volumes in a short time. Furthermore, this material makes it possible to print the next layer on the previous one in a short period of time due to quick solidification.

Process identification

Some experiments were carried out to identify the parameters of the Foam Additive Manufacturing (FAM) process model. The process model expresses the height of the deposited layer as a function of both the deposition speed, i.e., the spraying effector speed, and the deposition distance, i.e., the distance between the spraying nozzle and the preceding layer. The latter one is the deposition speed, namely the spraying effector speed regarding the printing surface. Fifteen experiments were performed with deposition speed varying from 0.05 m.s^{-1} to 0.25 m.s^{-1} and deposition distance varying from 0.05 m to 0.25 m.

Deposition speed (m.s^{-1})	Deposition distance (m) 0.10	0.15	0.20
0.050	0.071	0.068	0.064
0.075	0.057	0.056	0.045
0.100	0.043	0.043	0.034
0.150	0.036	0.027	0.021
0.250	0.024	0.018	0.013

TABLE 1: Measured layer height (m)

Single straight line layers were deposited using the CDPR on a flat surface (see Fig. 4). Table 1 gives the measured height of the printed samples after solidification as a function of the deposition distance and speed. The identified discrete values obtained after this experiment were fitted with a non-linear regression model as shown in Fig. 3.

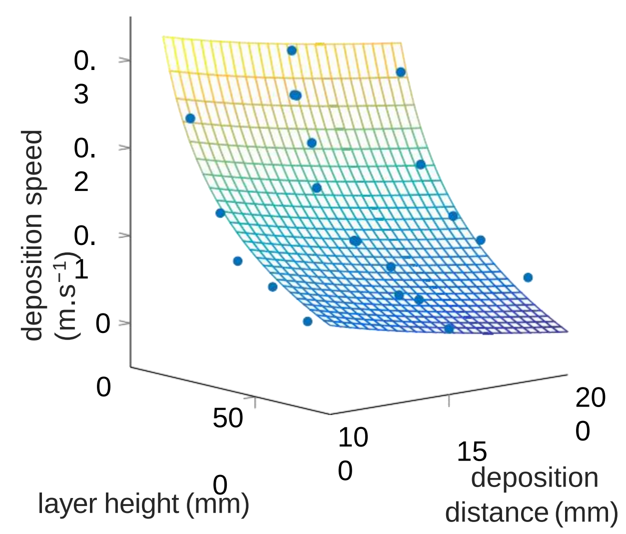

FIGURE 3: Process identification

FIGURE 4: Printed samples

Digital Twin

In our case, the creation of a digital twin of the YHNOVA house, allows to simulate the different scenarios of implantation of the house with different thicknesses of walls according to the geographical implantation without increasing the construction costs

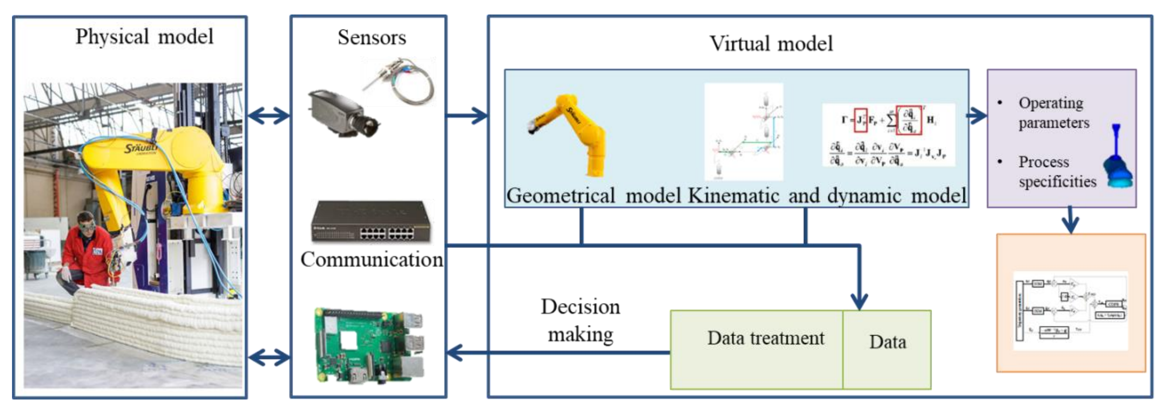

FIGURE 3: Proposal to set up a digital twin for field construction with 3d printing process

In our case, we will keep the different digital models of each phase which, in turn, will feed the single digital twin in order to simulate different morphologies of cords that will build the walls and to see the technico-economic impact of the implementation of the 3D printing process according to the thermal performances obtained during these different simulations. The digital twin allows us to analyze the influence of certain parameters such as: the solar flux, the thickness of the wall, the maximum and minimum temperature, and the temperature distributions of the components of the habitat according to the various thermal regulations in force in the field of construction. Finally, a data capitalization for the habitat can be realized for Yhnova with the help of sensors that have been set up to collect consumption data of the house and thus enrich the data of the digital twin set up.

Experimental validations

The use of a digital twin also allows us to simulate various operations of the second work with the aim of facilitating the installation of the second work (joinery, framework, green wall, window sill), such as the installation of joineries by adding insulating material on certain points (positioning, support, window sill, ...) according to the thicknesses of the walls of the simulated walls,

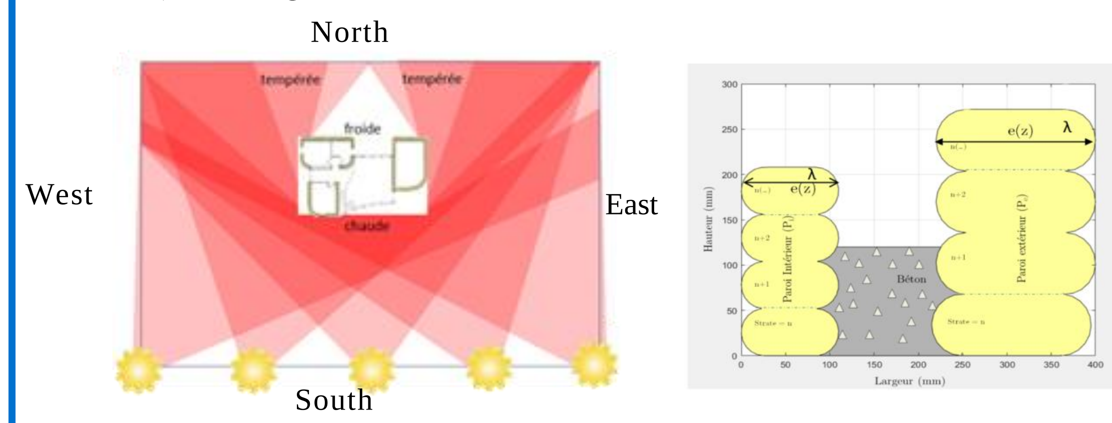

FIGURE 6 : The different wall thicknesses depending on the layout of the house

FIGURE 10: Expérimental validation

In conclusion, this paper details our contribution to the development of a digital twin based on genetic algorithms that allows us to functionalize the walls of a 3D printed house by taking into account the specificities of the geometry of the house and its orientation of implantations. In the innovative context of digital twins, models were created in order to better control and improve the thermal performance of the house by starting from the insulating functionality of the foam used for their manufacture with the constructive principle "Batiprint3D tm". The results obtained for the Yhnova house, the first social housing manufactured using 3D printing in Nantes in 2017, allow us to consider enriching the proposed approach by taking into account non-geometric constraints in order to optimize the thickness of the insulating parts of the manufactured walls according to the implementation of the house

References

1 Benoıt Furet, Philippe Poullain, and Se´bastien Garnier. "3D printing for construction based on a complex wall of polymer-foam and concrete". In: *Additive Manufacturing* 28 (2019). aug, pp. 58–64.

2 Philippe Poullain, Elodie Paquet, Se´bastien Garnier, Benoıt Furet, et al. "On site deployment of 3D printing for the building construction YhnovaTM". In: *MATEC Web of Conferences* 163 (2018), p. 01001.

3 Philippe Poullain, Andy Andrianandraina, Bogdan Cazacliu, Anne Ventura. « Sensitivity analysis of parameters influencing building heating energy consumption using hemp-lime material » First International Conference on Bio-based Building Materials, Jun 2015, Clermont-Ferrand, France. (hal-01164108)

4 G.L. Knapp, T. Mukherjee, J.S. Zuback, H.L. Wei, T.A. Palmer, A. De, T. DebRoy,Building blocks for a digital twin of additive manufacturing,Acta Materialia, Volume 135, 2017, Pages 390-399,ISSN 1359-6454,

5 T. Mukherjee, T. DebRoy,A digital twin for rapid qualification of 3D printed metallic components,Applied Materials Today,Volume 14,2019,Pages 59-65, ISSN 2352-9407,

Contact: Elodie.paquet@univ-nantes,fr

Acknowledgments: The authors would like to thank the staff of the IUT of Nantes and Saint-Nazaire for their support and help.