

A BIM-based circularity assessment methodology towards sustainable buildings refurbishment design

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MIT Portugal

2022 Annual Conference

Research Motivation and Objectives

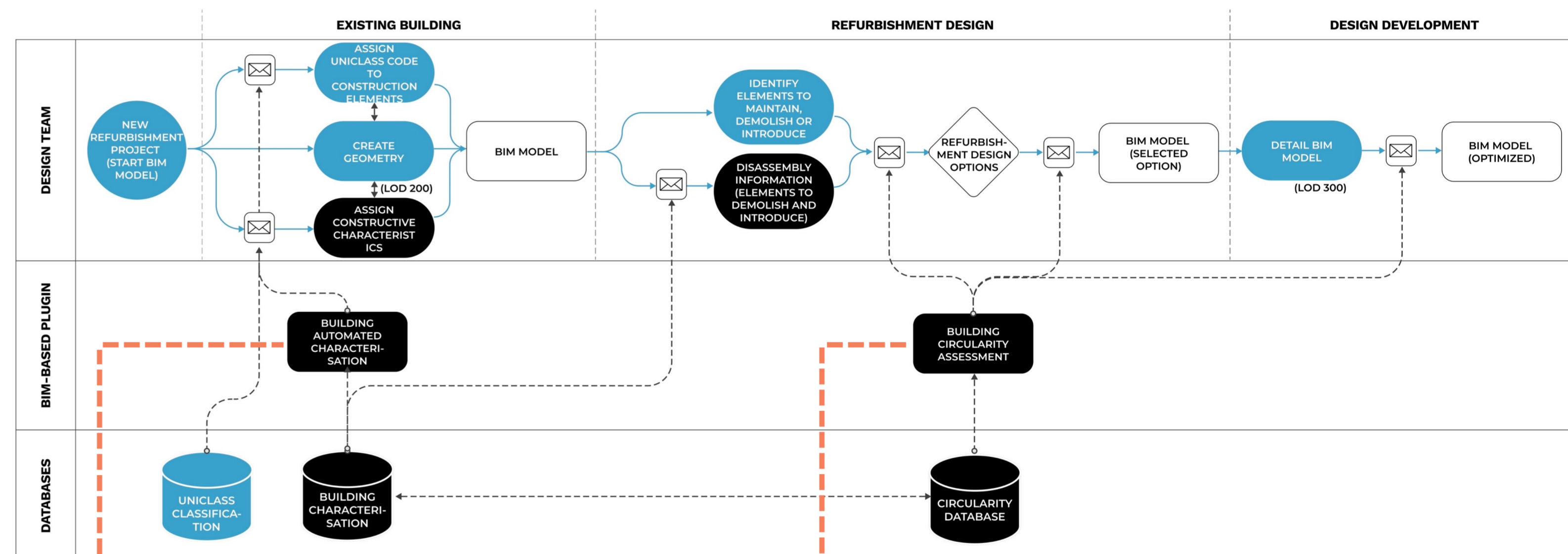
Construction industry is responsible for over 30% of the global extraction of natural resources and 25% of solid waste generated [1], whereas only 20%-30% of construction and demolition waste is recovered [2]. Improving this situation is at the core of Circular Economy (CE), which is intended to reduce natural resource extraction, by minimizing waste, materials and energy consumption and extending and maximizing the use of materials and existing structures [3].

The lack of standard practices and platforms for assessing refurbishment strategies towards Circular Economy (CE) and their impact in global warming constitutes a challenge for the decarbonisation of existing building stock. Incorporating data and feedback from designers and practitioners since early design stages is important to feed a multi-criteria dynamic process with multiple dimensions, which must be assessed under a life cycle perspective. To tackle this issue, this research introduces a new methodology to support the implementation of tailored refurbishment strategies for increased recovery, reuse and recycling of construction materials. The final objective is to build a methodological framework for sustainable refurbishment design in a BIM environment, which aims to facilitate standardised practices in the construction sector, regarding CE, with a positive impact in the mitigation of global warming and the decarbonisation of the building stock. To test the development of this methodology, a case study building in Lisbon, corresponding to a 1919-1945 archetype is analysed, making use of its BIM model, where BIM standardisation criteria and circularity indicators are discussed, in order to be implemented as a Plugin for Circularity.

Methods

First, the existing building is in the BIM software and assembly codes and construction properties are assigned to each construction element. If construction information is unknown, a Building Automated Characterisation (BAC), based on Archetypes [4], can be performed. Afterwards, the elements to be maintained, demolished or created are identified in the BIM model and their interconnections are characterised, making use of predefined alternatives, through the BAC or inserted directly by the user. The Circularity Assessment by a BIM-based plugin, and the scores for Circularity Indicators [5-6] are quantified. New refurbishment options can be simulated anytime, resulting in new Circularity Assessments, until the selection of the optimised design, which will be detailed for construction.

BIM-based circularity assessment for refurbishment design conceptual workflow



Preliminary Results

Archetypes Characterisation

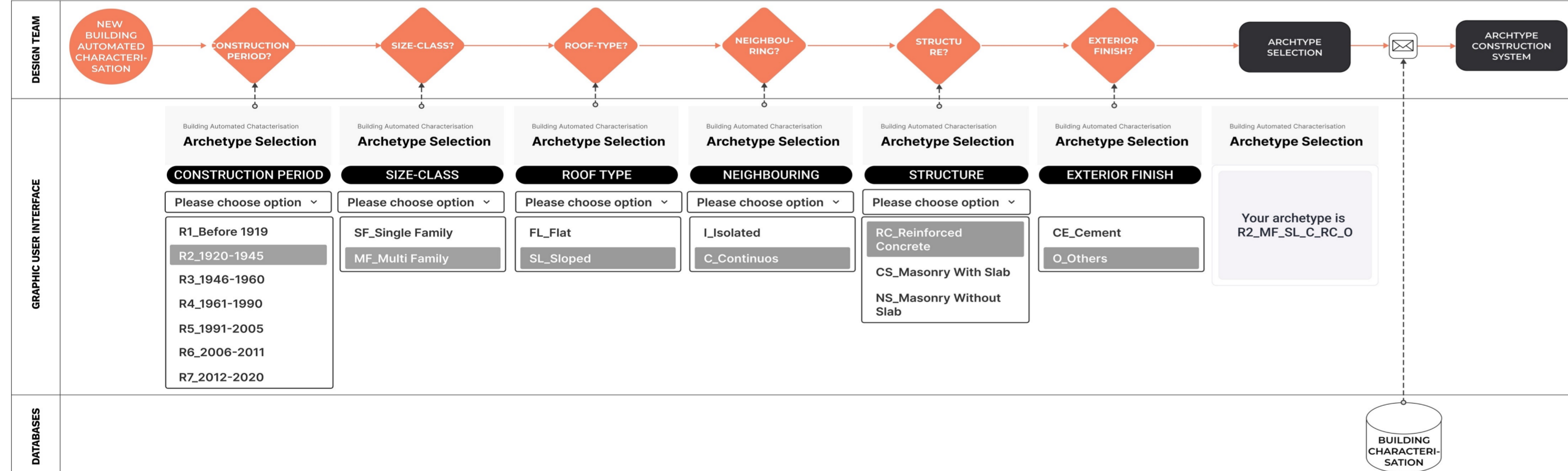
Statistical Data + Literature Review

- 200 Residential archetypes
- 100 Non residential archetypes

MAIN USE	CONSTRUCTION PERIOD	SIZE-CLASS	ROOF TYPE	NEIGHBOURING	STRUCTURE	EXTERIOR FINISH
INE	INE	INE	INE	INE	INE	INE
Year	2011	2011	2011	2011	2011	2011
RL Residential	RL_Before 1919	SF_Single Family	FL_Flat	I_Isolated	RC_Reinforced Concrete	CE_Cement
NR_Non residential	R2_1920-1945	MF_Multi Family	SL_Sloped	C_Continuous	CS_Masonry With Slab	O_Others
	R3_1946-1960				NS_Masonry Without Slab	
	R4_1961-1990					
	R5_1991-2005					
	R6_2006-2011					
	R7_2012-2021					

Material-related

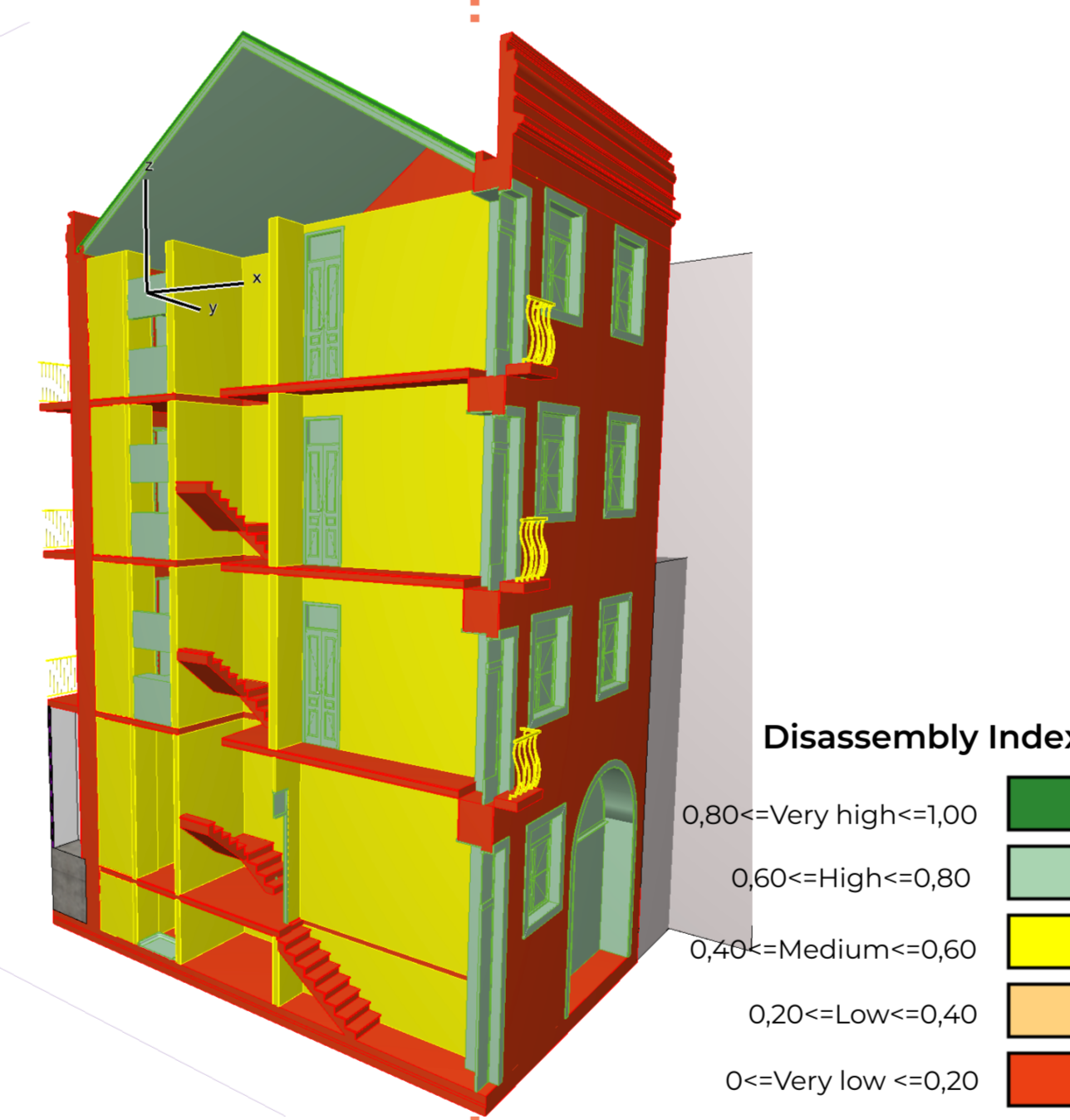
BAC Workflow and Graphic User Interface (GUI)



BAC Outputs

Classification	Construction Element	Adjacent elements	Connection Type	Connection accessibility	Coverage	Form Containment
Roof	Roof structure	Dry structure	Dry Connection	Freely Accessible	Molecular zoning of objects	Open, no inclusions
Exterior walls - main facade	Exterior walls + structure: Doors, Windows, Glass, Cladding	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Open, no inclusions	Open, no inclusions
Exterior walls - back facade	Exterior walls + structure: Doors, Windows, Glass, Cladding	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Open, no inclusions	Open, no inclusions
Exterior walls - side facade	Exterior walls + structure: Doors, Windows, Glass, Cladding	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Open, no inclusions	Open, no inclusions
Doors - main	Exterior walls	Connection with added elements	Freely Accessible	Molecular zoning of objects	Closed on one side	Closed on one side
Doors - frames	Exterior walls	Connection with added elements	Accessibility with additional actions with separate	Molecular zoning of objects	Closed on one side	Closed on one side
Windows - main	Exterior walls	Connection with added elements	Accessibility with additional actions with separate	Molecular zoning of objects	Closed on one side	Closed on one side
Windows - frames	Exterior walls	Connection with added elements	Accessibility with additional actions with separate	Molecular zoning of objects	Closed on one side	Closed on one side
Structure - Foundation	Beating exterior walls, Cellings	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Closed on several sides	Closed on several sides
Floors	Beating exterior walls, Cellings	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Closed on several sides	Closed on several sides
Beating exterior walls - facade	Exterior walls, Roofs, Doors, Windows, Glass, Cladding	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Closed on several sides	Closed on several sides
Beating exterior walls - side facade	Exterior walls, Roofs, Doors	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Closed on several sides	Closed on several sides
Balcony	Exterior walls, Slabs	Hard chemical connection	Accessibility with additional actions with separate	Full integration of objects	Closed on one side	Closed on one side
Space Plan - Interior Walls	Beating exterior walls, Cellings	Hard chemical connection	Accessibility with additional actions with separate	Crossings between one or more objects	Open, no inclusions	Open, no inclusions
Walls	Exterior walls, Slabs, Cellings	Hard chemical connection	Accessibility with additional actions with separate	Crossings between one or more objects	Open, no inclusions	Open, no inclusions
Ceilings	Exterior walls, Slabs, Cellings	Hard chemical connection	Accessibility with additional actions with separate	Crossings between one or more objects	Open, no inclusions	Open, no inclusions
Floors	Exterior walls, Slabs, Cellings	Hard chemical connection	Accessibility with additional actions with separate	Crossings between one or more objects	Open, no inclusions	Open, no inclusions
Doors - main	Exterior walls	Connection with added elements	Accessibility with additional actions with separate	Molecular zoning of objects	Closed on one side	Closed on one side
Doors - frames	Exterior walls	Connection with added elements	Accessibility with additional actions with separate	Molecular zoning of objects	Closed on one side	Closed on one side
Partitions	n.a.	n.a.	Freely Accessible	Free access	Closed on one side	Closed on one side
Stairs	Floors, Interior walls	Dry Connection	Freely Accessible	Free access	Closed on one side	Closed on one side
Kitchens	Floors, Interior walls	Dry Connection	Freely Accessible	Free access	Closed on one side	Closed on one side

BIM-based Plugin GUI: Circularity Assessment



Adoption of Circularity indicators

Material Circularity Indicator: $MCI_j = \max \left(0, 1 - \frac{0.9}{X_j} LFI_j \right)$

LFI_j - Linear Flow Index for product j
 X_j - Product Utility

Product Circularity Indicator: $PCI_j = MCI_j \frac{1}{F_d} \sum_{i=1}^n F_{i,j}$

MCI_j - Material Circularity Indicator
 $\frac{1}{F_d} \sum_{i=1}^n F_{i,j}$ - Disassembly Index

System Circularity Indicator: $SCI_j = \frac{1}{M_j} \sum_{i=1}^n M_i PCI_i$

M_j - Total mass of all components belonging to the layer s
 J_s - Total number of components belonging to the layer s
 M_j - Mass of the element j
 PCI_j - Product Circularity Indicator

Building Circularity Indicator: $BCI_a = \frac{1}{LK} \sum_{s=1}^S LK_s SCI_s$

$\sum_{s=1}^S LK_s$ - Sum of all the LKs weights for each layer

Future Work

- Improve data collection and organisation
- Define the optimal detail level of information for each construction element and its impact in Circularity Assessment
- Develop the BIM-based plugin
- Develop guidelines for BIM-based buildings passports

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Funded by: