Life cycle façade refurbishment for post-war residential buildings

Paressa Loussos, 1373528

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Delft University of Technology
MSc Graduation, Building Technology

First mentor:	A.C. Bergsma
Second mentor:	A.A.J.F. van den Dobbelsteen
Third mentor:	T. Konstantinou
External Examiner:	R. Binnekamp

Contents

Introduction – Problem statement

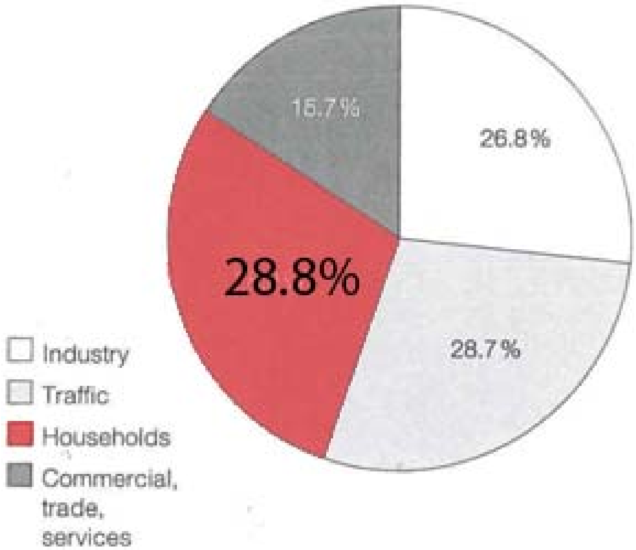
Problem Statement

-*Global warming* by GHG by fossil-fuels

-90+% still fossil fuels used

-Depletion of these *fossil fuels*

-*Energy demand* needs to be *lowered*



Energy consumption in Germany in 2005
Source: Hegger et al. (2008)

Residential buildings

-40% of the GHG by buildings

-28,8% of energy use is by households

-50% of Dutch buildings built before 1970, large part not insulated well

-Energy use of buildings lowered by refurbishment, savings possible of 75% (energy label G to A).

Introduction – Life cycle energy

Life cycle energy (Joule)

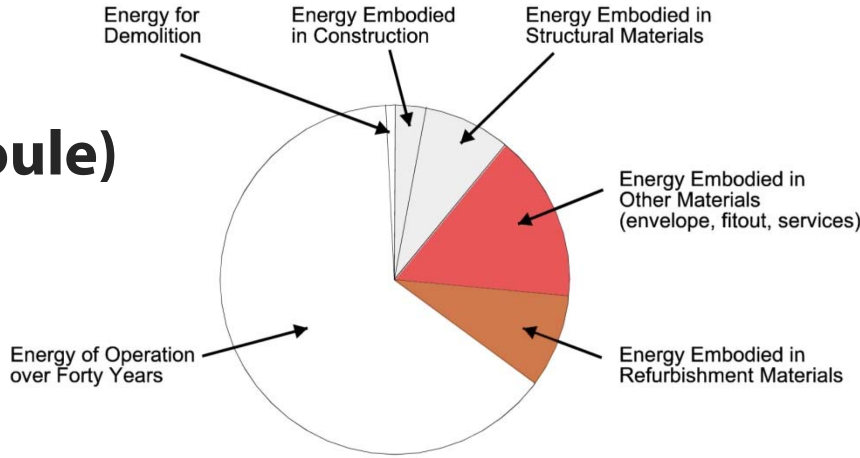
-Embodied energy

-*Initial embodied energy* (extraction, processing, manufacturing, transportation, assembly)

-*Recurring embodied energy* (refurbish and maintenance)

-Operation energy

-Demolition energy



Source: Crowther (1999)

Embodied energy in buildings (Joule)

-10-40% of total Energy

-40% reduction possible with reused and recycled materials

Environmental impact (euro)

-Also includes global warming potential, ozone depletion potential etc.

-Can be expressed in environmental costs

Introduction – Goal

Goal

-*Develop a* ***design approach*** for residential buildings, to improve the Life cycle energy (operation + embodied) and environmental impact

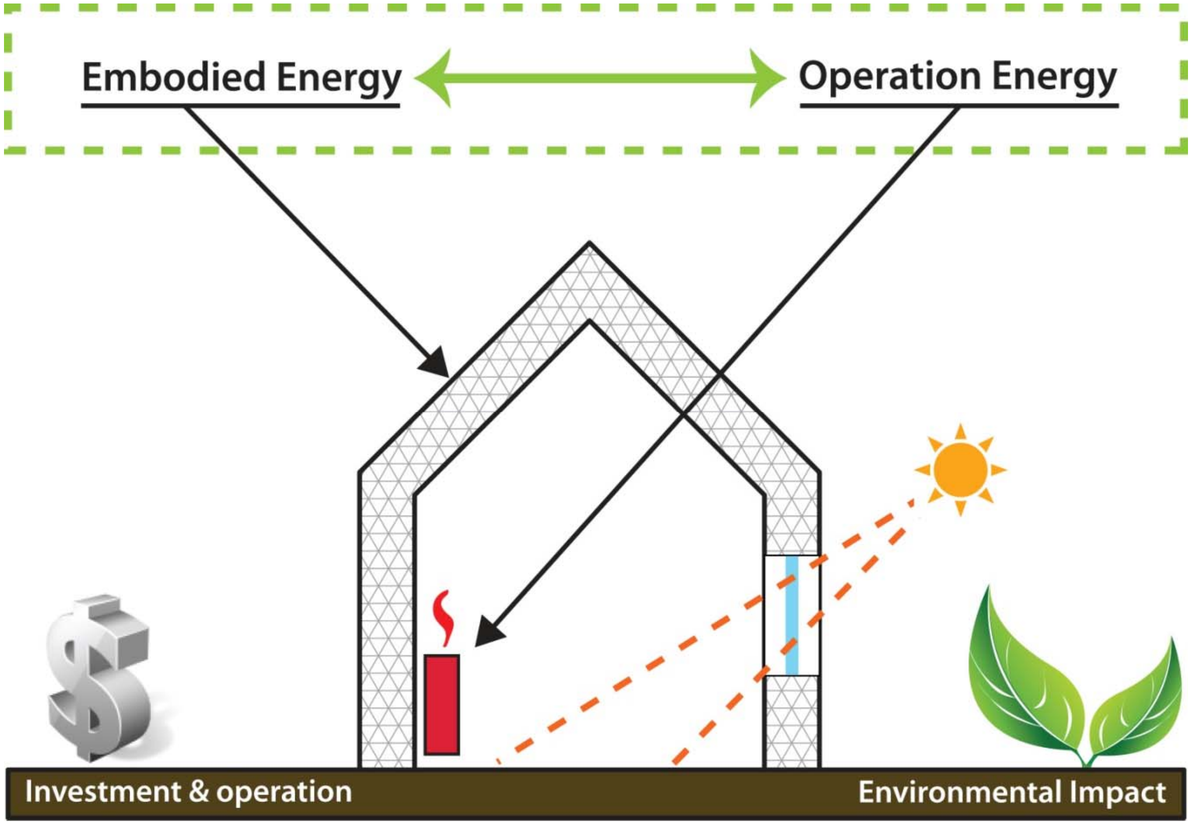
-*Give* ***recommendations*** for other designers concerning materials for refurbishment

-Show possibilities for ***future research***

Introduction – Research questions

Main research question

How can the façade of a post-war residential building be refurbished, to make the **operation energy and embodied energy (life cycle energy) as low as possible**, while also considering other factors that influence the environmental impact?



Introduction – Research questions

Sub research questions

Refurbishment	1. What measures can be taken to improve the façade of a (residential) building with refurbishment?
Energy performance	2. How can the façade be upgraded to increase the energy performance of a (residential) building?
Case study building	3. What type of building can best be used for the case study design?
Design approach	4. What approach can be used to lower the energy use and environmental impact in façade refurbishment of a residential building, (and how can this be implemented onto the case study)?
Materials	5. What materials can best be used in the façade (for refurbishment) to lower the environmental impact, with a focus on the embodied energy?
Reuse/recycling	6. How can reusing and recycling of (façade) materials contribute to lower the environmental impact, with a focus on the embodied energy?

Introduction – Boundary conditions

Tools

-Operation energy: EPC, Enorm

-Embodied energy: NIBE database, Excel

-Environmental costs: NIBE database, Excel

-Building costs: NIBE database, Excel, internet

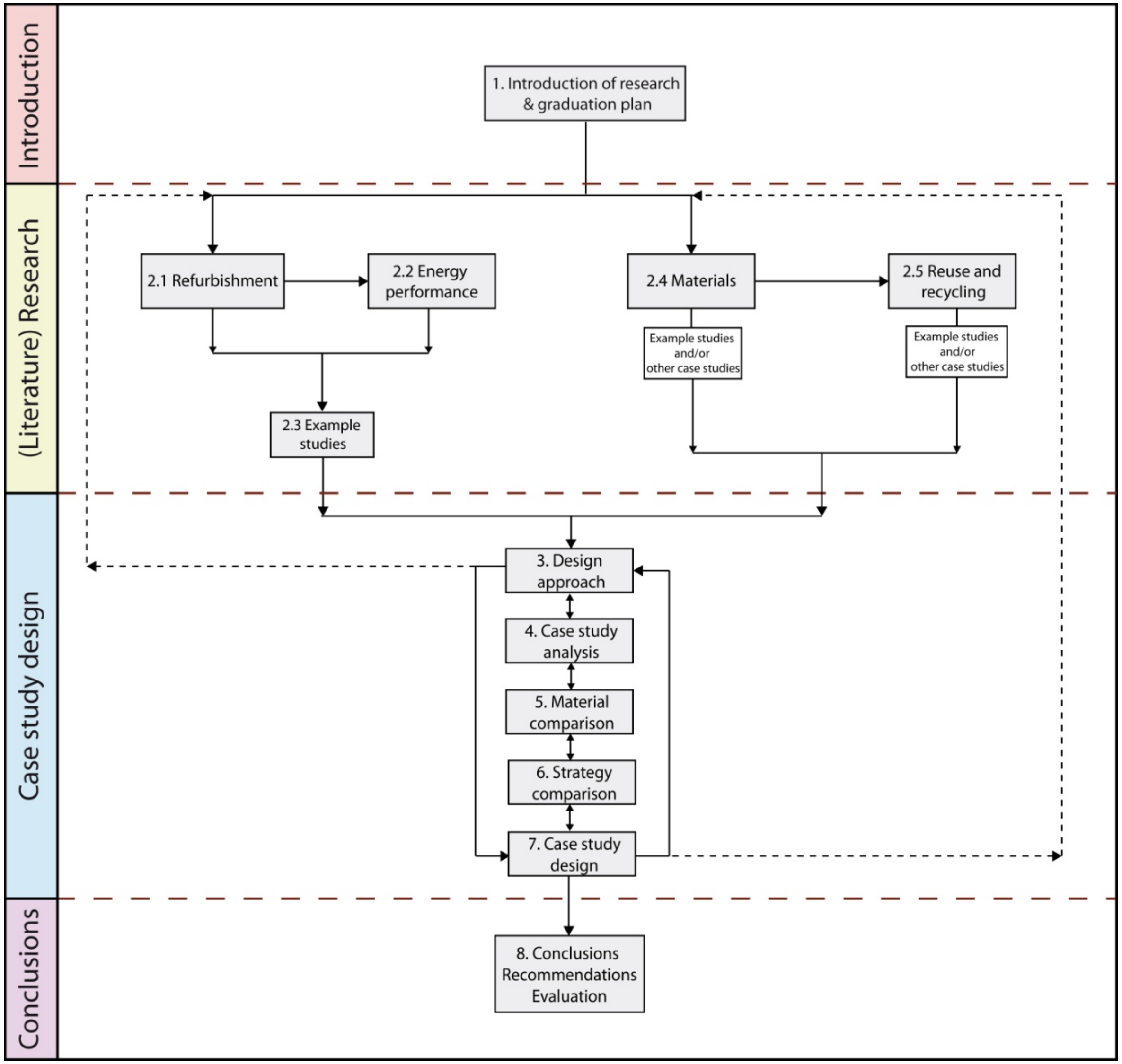
Research focus

-Refurbishment of residential buildings

-Design for one case study, focus on façade

-Assessment of energy performance, material properties, environment

Structure of research thesis



Literature research - Refurbishment

Sub research question

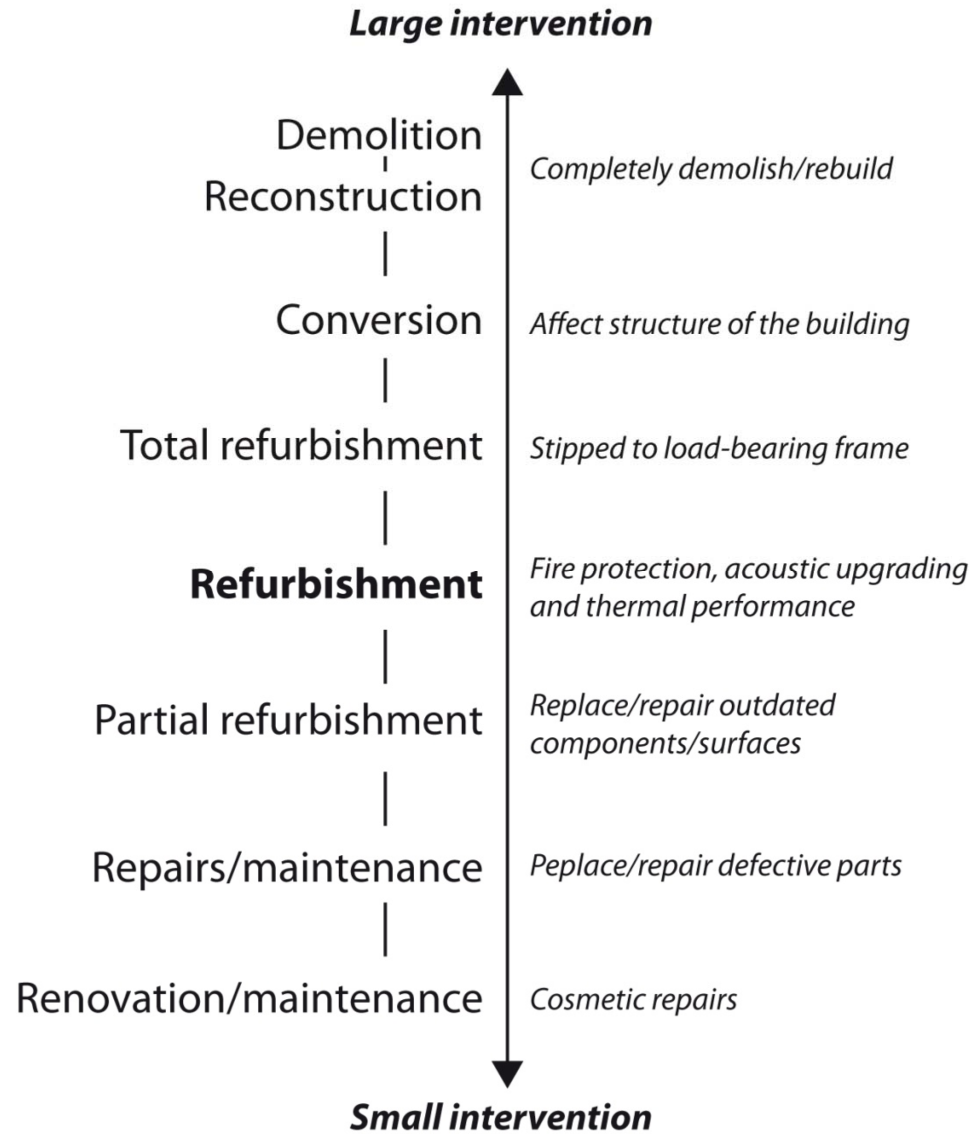
1. What measures can be taken to ***improve the façade*** *of a (residential) building with refurbishment?*

Literature research - Refurbishment

Definitions

In refurbishment not only the defective building components are repaired or replaced, but also the outdated components or surfaces.

Upgrading in fire protection, acoustics and thermal performance



Literature research - Refurbishment

Strategies

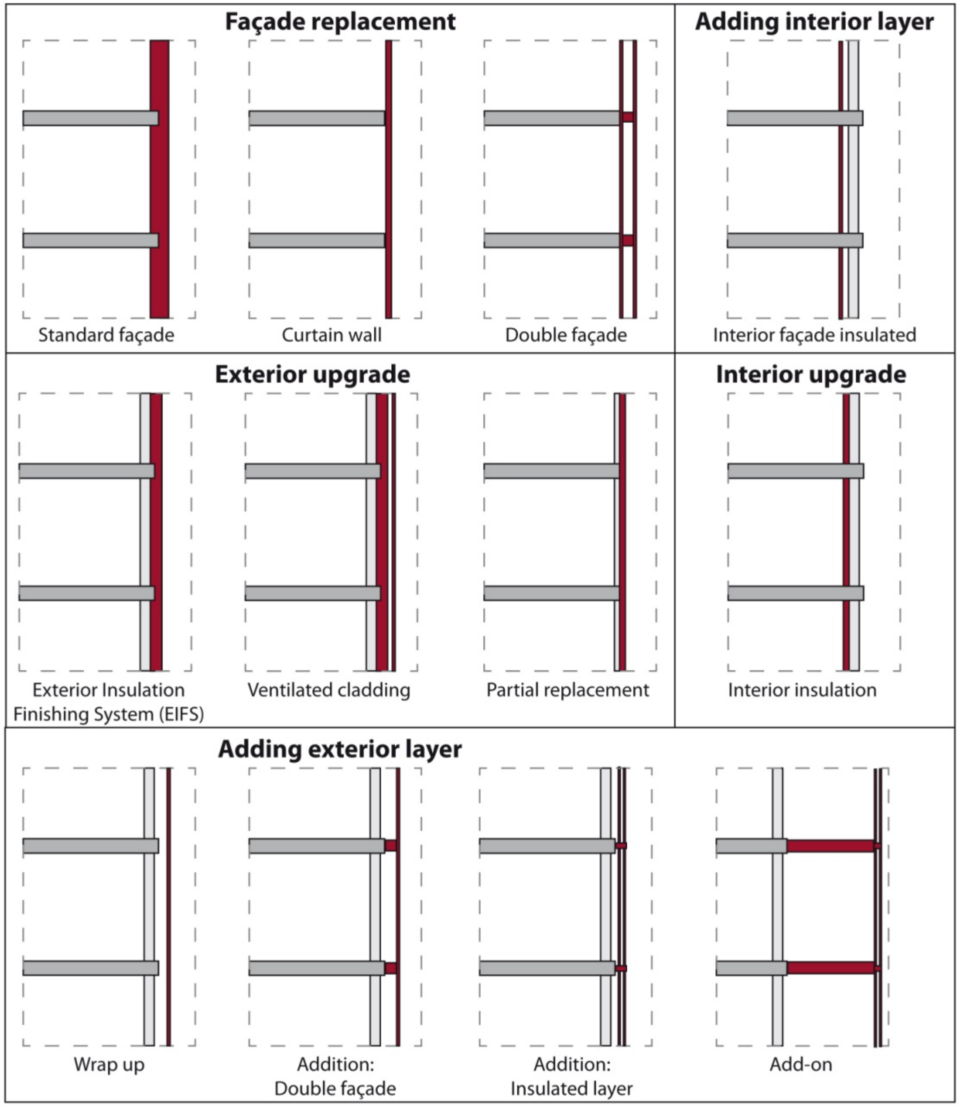
-Façade replacement

-Exterior addition

-Exterior upgrade

-Interior addition

-Interior upgrade



Literature research – Energy

Sub research question

2. How can the façade be upgraded to ***increase the energy performance*** *of a (residential) building?*

-Improving insulation

-Ventilation

-Domestic hot water/heating system

-Existing components and new sustainable materials

-Avoid overheating

-Daylighting, efficient lighting and control systems

-Efficient appliances and controls

Literature research – Case study

Sub research question

*3. What **type of building** can best be used for the **case study design**?*

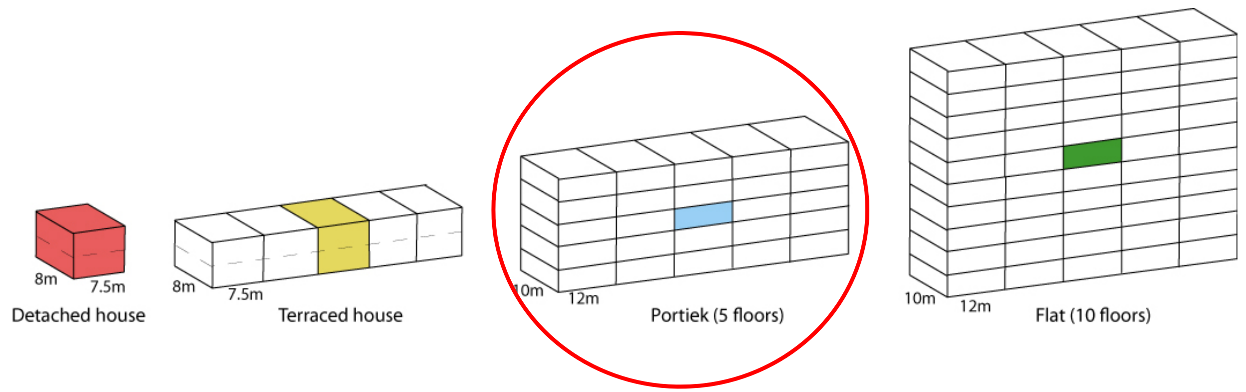
-Building period analysis

-Building type analysis

-Energy performance for different building types and periods

-Environmental costs per building type (Greencalc+)

-Example studies



Literature research – Case study

Conclusions

-Building period 1945-1975

-Portiek flat

-More types of façade materials/construction types

Literature research – Case study

Conclusions

-Building period 1945-1975

-Portiek flat

-More types of façade materials/construction types

Marco Pololaan, Kanaleneiland, Utrecht

PORTAAL

-Residential building from 1960's

-Portiek flat

-Different façade materials

-Bad energy performance (Label F/G)

-Renovation of 4 flats by **Portaal**

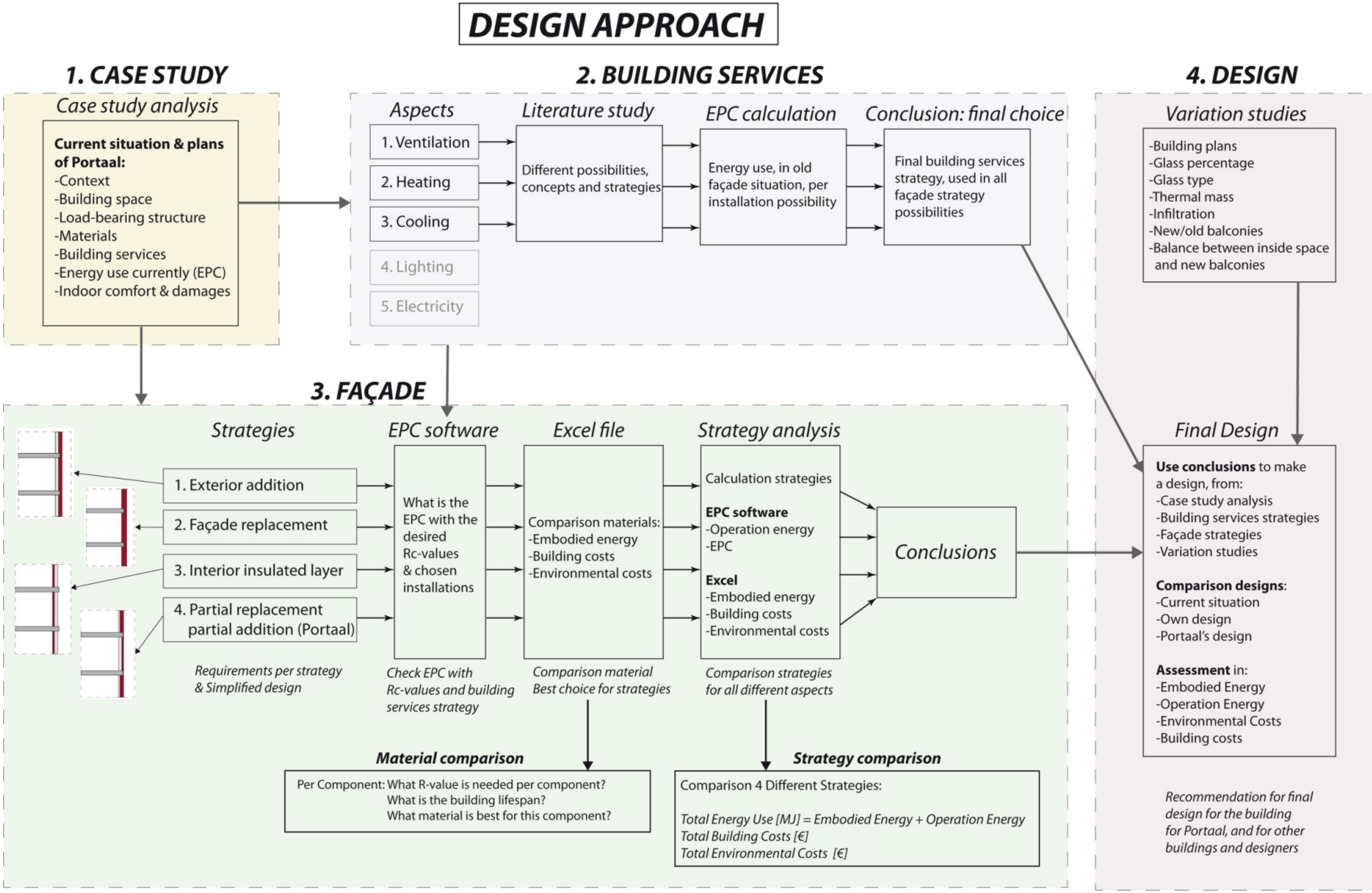
-Lifespan of 35 years after renovation

Design approach

Sub research question

*4. What **approach** can be used **to lower the energy use** and environmental impact in façade refurbishment of a residential building, (and how can this be implemented onto the case study)?*

Approach


DESIGN APPROACH
1. CASE STUDY
Case study analysis
Current situation & plans of Portaal:
-Context
-Building space
-Load-bearing structure
-Materials
-Building services
-Energy use currently (EPC)
-Indoor comfort & damages
2. BUILDING SERVICES
Aspects
1. Ventilation
2. Heating
3. Cooling
4. Lighting
5. Electricity
Literature study
Different possibilities, concepts and strategies
EPC calculation
Energy use, in old façade situation, per installation possibility
Conclusion: final choice
Final building services strategy, used in all façade strategy possibilities
4. DESIGN
Variation studies
-Building plans
-Glass percentage
-Glass type
-Thermal mass
-Infiltration
-New/old balconies
-Balance between inside space and new balconies
3. FAÇADE
Strategies
1. Exterior addition
2. Façade replacement
3. Interior insulated layer
4. Partial replacement partial addition (Portaal)
Requirements per strategy & Simplified design
EPC software
What is the EPC with the desired Rc-values & chosen installations
Check EPC with Rc-values and building services strategy
Excel file
Comparison materials:
-Embodied energy
-Building costs
-Environmental costs
Comparison material
Best choice for strategies
Strategy analysis
Calculation strategies
EPC software
-Operation energy
-EPC
Excel
-Embodied energy
-Building costs
-Environmental costs
Comparison strategies for all different aspects
Conclusions
Material comparison
Per Component: What R-value is needed per component?
What is the building lifespan?
What material is best for this component?
Strategy comparison
Comparison 4 Different Strategies:
Total Energy Use [MJ] = Embodied Energy + Operation Energy
Total Building Costs [€]
Total Environmental Costs [€]
Final Design
Use conclusions to make a design, from:
-Case study analysis
-Building services strategies
-Façade strategies
-Variation studies
Comparison designs:
-Current situation
-Own design
-Portaal's design
Assessment in:
-Embodied Energy
-Operation Energy
-Environmental Costs
-Building costs
Recommendation for final design for the building for Portaal, and for other buildings and designers

Design approach

Simplified approach

1. CASE STUDY ANALYSIS
- -Current situation
- -Plan portaal

↓

2. BUILDING SERVICES
- -Literature study
- -EPC calculations
- -Strategy choice

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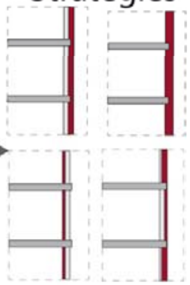
3. FAÇADE
- -Material comparison
- -Strategy comparison

→ Strategies



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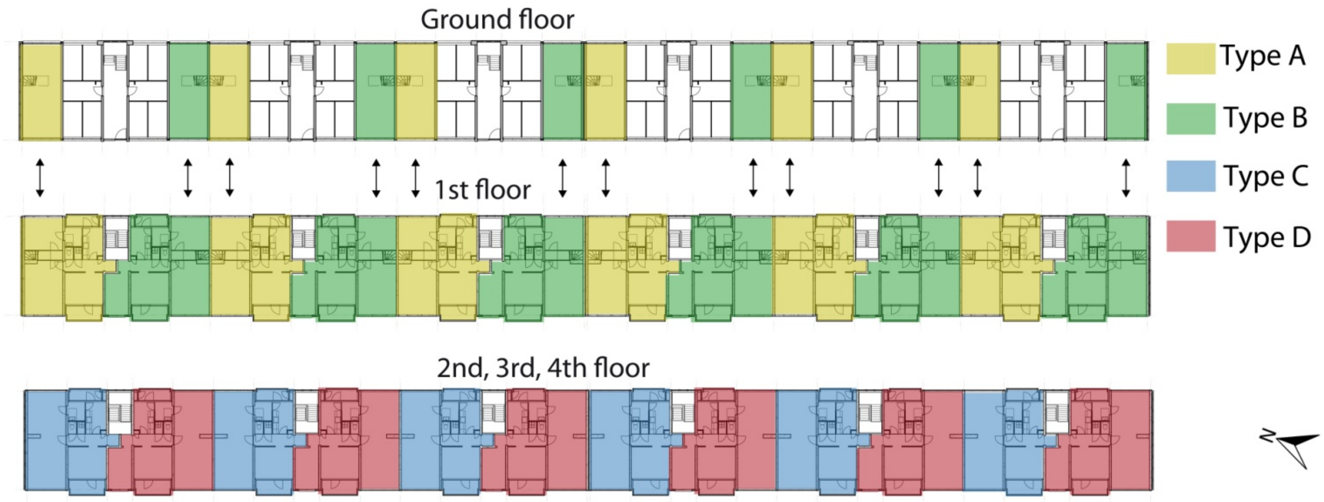
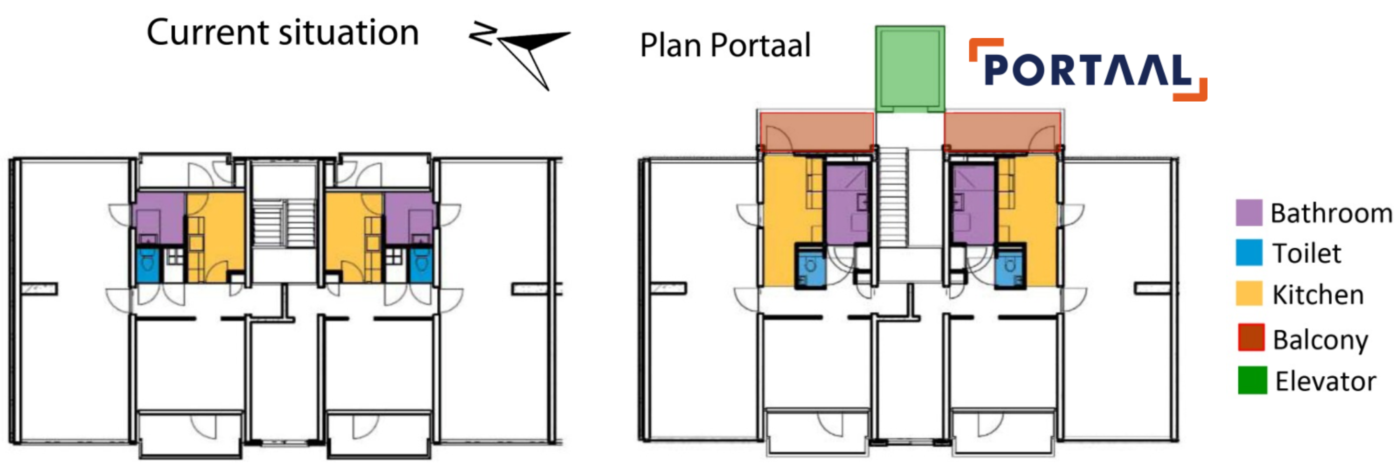
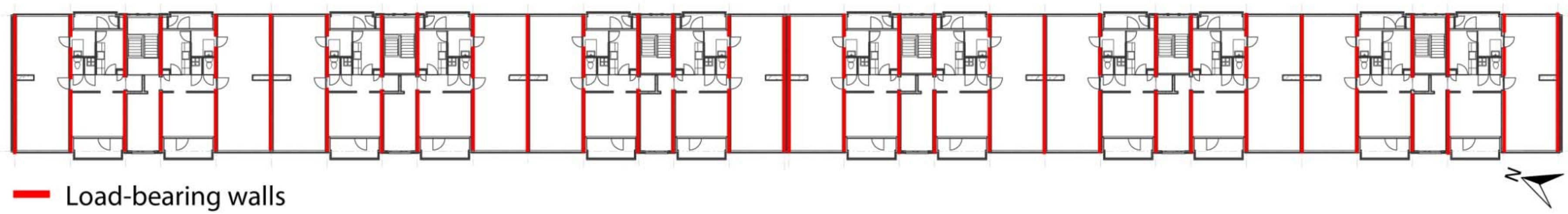
4. DESIGN
- -Variation studies
- -New design
- -Comparison to old & Portaal

Building space





Load-bearing structure



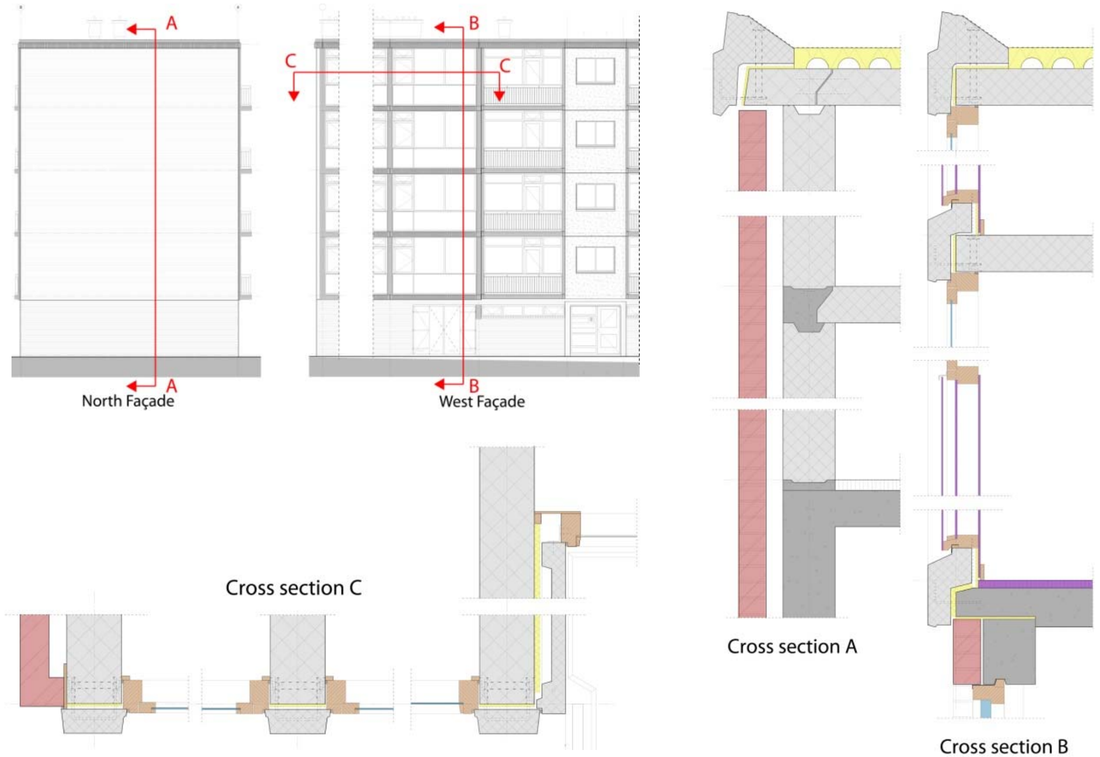
Materials

-South and North: Masonry

-Prefab concrete elements

-Plates in wooden frames

-Single glazing



Case study analysis

Building Services

-District heating

-Electric boiler for warm water

-Radiators

-Natural ventilation

Plan Portaal: add mechanical exhaust

Indoor comfort

-Cold draught due to single glass and ventilation

-Acoustics from inside and outside

Energy Index

-Label F to G

-Top right apartment has highest Index EI = 3.28

EPC

-EPC = 2.99

-Operation Energy/ year =138.000 MJ

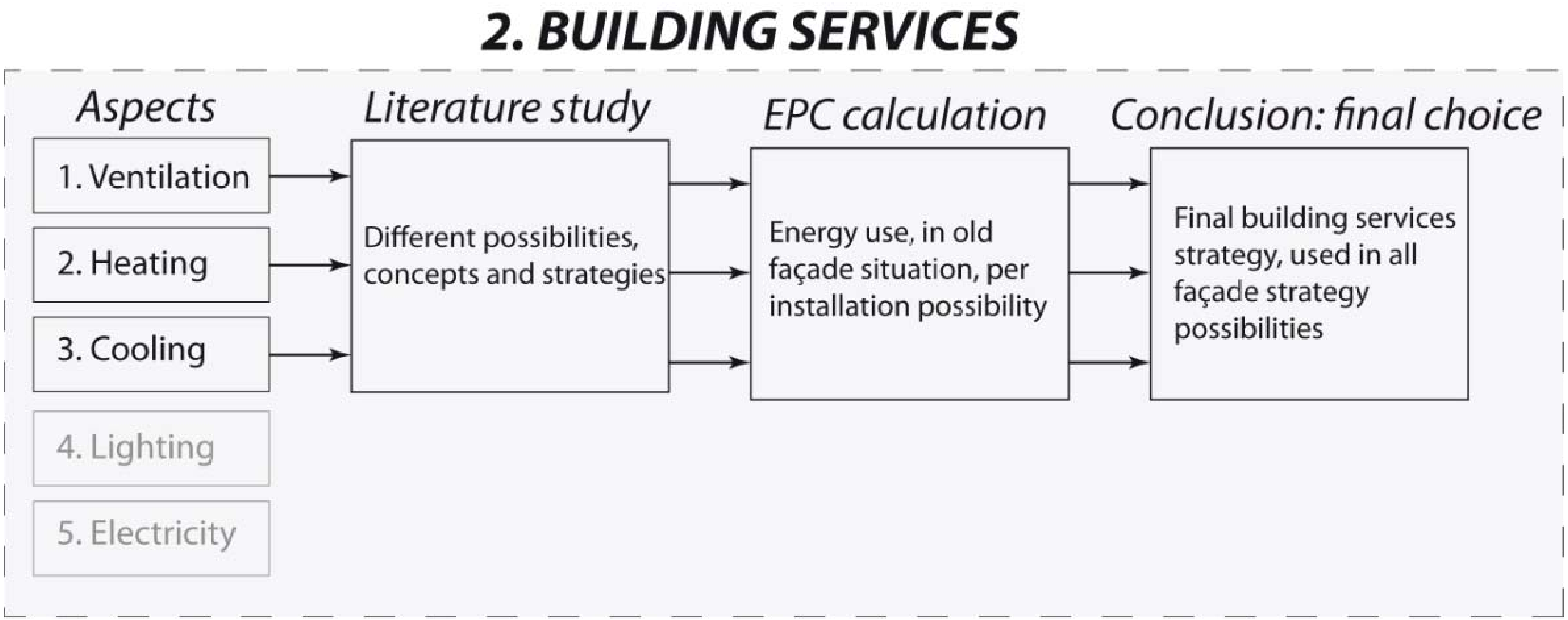
-Heating/year = 99.200MJ

Improvement insulation

If insulation is improved to

Rc=3.5m2K/W → EPC = 1.59

Building Services - Approach



Building Services - Analysis

Ventilation

	Comfort	Sound	Space use	Costs	Energy use system	Heat savings	EPC reduction
Natural	-	++	++	++	++	- -	None
Mech. Supply							+/-
Mech.Exhaust	+/-	+/-	+	+	+/-	+/-	+
Mechanical	++	-	- -	-	-	+	+
Local unit	++	-	+/-	-	+/-	+	+

Heating

	Sub type	Availability & Costs	Suitability with ventilation & heat output system		EPC reduction compared to old situation, district heating
			Low T	High T	
Fossil fuels	CV heating	+	+	+	+/-
Electric heating	CV heating	+	+	+	- -
Biomass	Wood/Biomass	+/-	+	+	+/-
Solar heat collectors	Unglazed	-	+	+	++
	Flat-plate	-	+	+	++
	Air collector	-	+	+	++
	Vacuum-tube	-	+	+	++
Combined Heat & Power	Micro CHP	-	+	+	+/-
	District heating	+	+	+	+/-
Heat pump	External air	+	+	-	++
	Shallow soil	- -	+	-	++
	Deep ground	+/-	+	-	++
	Ground/surface water	-	+	-	++
	Waste heat	+	+	-	+
Heat storage	Short-term	+/-	+	-	
	Long-term	-	+	-	++

Building Services - Conclusions

Conclusions Building Services

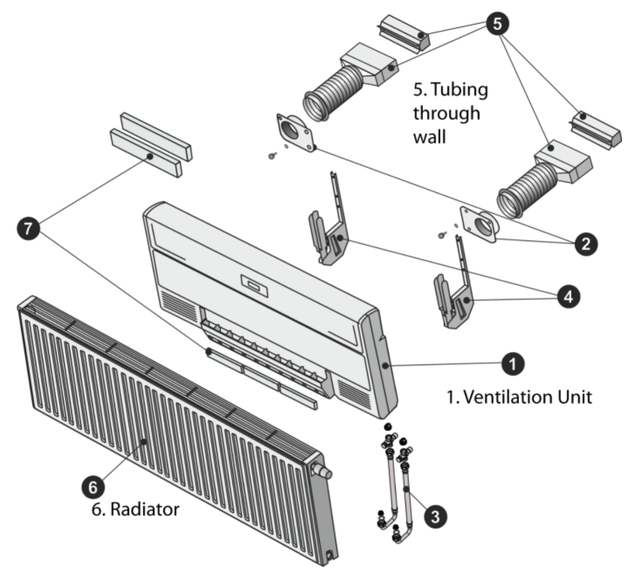
-**Heat pump** with **groundwater storage** for heating (low temperature)

-**District heating** (already present) for domestic hot water

-**Local units** underneath windows, with CO2 sensors and **heat recovery** for ventilation

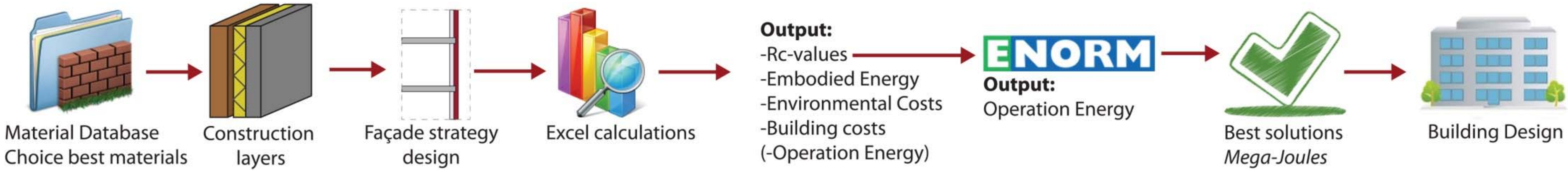
-EPC improved from 1.59 → 0.76

Climarad system

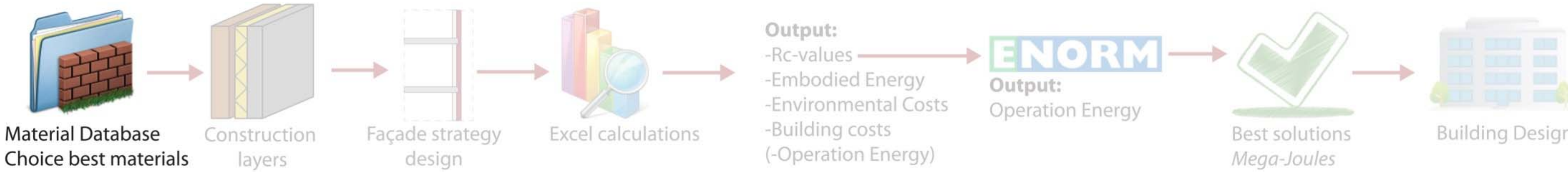


Façade analysis - Approach

Façade design approach



Façade design approach – Material database



	CAVITY INSULATION (m2)	λ [W/mK]	U-value (W/m2K)	Embodied energy/m3 MJ	Thickness for Rc 3,5 (m)	kgCO2eq/FE per 1 life span	Life span (years)	Environm. Costs/m3 per life span	Building costs/m3 (euro) per life span	Material reuse H
NEW FACADE	Glaswol platen	0,035		677	0,120	5,23	75	6,42	92	35
	BIO-EPS	0,038		1521	0,140	13,7	75	7,79	0	3
	EPS platen	0,040		1827	0,120	14,1	75	9,25	100	3
	Steenwol platen	0,035		1285	0,120	9,92	75	10,33	108	7
	Purschuim platen	0,023		3469	0,082	18,3	75	19,88	232	6
	Resolschuim platen	0,021		3191	0,076	15,6	75	23,16	316,48	3
	Houtvezel flexibele isolatie	0,038		866	0,140	7,8	40	6,32	166,97	28
	Vlasplaten (incl. PE-folie)	0,035		965	0,120	7,45	40	8,63	128,67	0
	Celluloseplaten (incl. PE-folie)	0,039		655	0,140	5,9	30	5,19	0	0
	Cellulair glas	0,041		3264	0,140	29,4	100	21,29	386	36
	Kurkplaten, geëxpandeerd	0,040		3009	0,140	27,1	75	29,36	0	29
	XPS platen	0,038		7395	0,140	66,6	75	31,00	293	3
	Schapenwol (incl. PE-folie)	0,035		24224	0,120	187	75	308,83	150	28
COMBINATION	Glaswool plates + wooden frame	0,060		835			75	7,87	131	
OLD FACADE	Polystyrene old	0,080		2340						

	FLAT ROOF INSULATION (m2)	λ [W/mK]	U-value (W/m2K)	Embodied energy/m3 MJ	Thickness for R 3,5 (m)	kgCO2eq/FE per 1 life span	Life span (years)	Environm. Costs/m3 per life span	Building costs/m3 (euro) per 1 life span	Material reuse H
NEW FACADE	EPS plates	0,0343		1827	0,120	14,1	75	9,25	142	3
	Resolfoam plates	0,021		3634	0,080	18,7	75	26,38	0	2
	PUR (pentane blown)	0,023		4566	0,096	28,2	75	25,42	271	4
	Cellulair glass	0,0423		3264	0,150	31,5	75	21,27	427	36
	Cork; expanded	0,04		3009	0,140	27,1	75	29,36	0	29
	Rockwool plates	0,039		4019	0,140	36,2	75	32,21	150	7

	OUTSIDE WINDOW FRAME (per m1)	λ [W/mK]	U-value (W/m2K)	Embodied energy/m3	Dimensions (mmxmm)	kgCO2eq/FE per 1 life span	Life span (years)	Environm. Costs/m3 per life span	Building costs/m3 per 1 life span	Material reuse H
NEW FACADE	European Hardwood (renewably grown)	0,274	2,40	3511	114x67	1,725	50	30,11	6743	32
	European Softwood (renewably grown)	0,274	2,40	2747	114x67	1,35	35	22,69	0	31
	European Hardwood (normal grown)	0,274	2,40	3511	114x67	1,725	50	37,31	6415	32
	European Softwood (normal grown)	0,274	2,40	2686	114x67	1,32	35	27,06	0	31
	Tropical hardwood (renewably grown)	0,274	2,40	7662	114x67	3,765	50	84,45	7332	31
	Aluminium 97% secundary, anodised	0,156	2,29	34216	68x62	9,28	75	329,70	0	74
	Aluminium 47% secundary, anodised	0,156	2,29	34179	68x62	9,27	75	417,46	19450	63
	Aluminium 97% secundary, coated	0,156	2,29	30382	68x62	8,24	75	426,94	0	77
	Aluminium 47% secundary, coated	0,156	2,29	30345	68x62	8,23	75	514,71	19450	66
	PVC on steel core	0,224	2,00	18130	112x80	10,45	40	150,67	3795	51
	Tropical hardwood (normal grown)	0,274	2,40	7662	114x67	3,765	50	571,48	6415	31
OLD FACADE	Hardwood old	0,200		1550						

Façade analysis – Materials

Material analysis

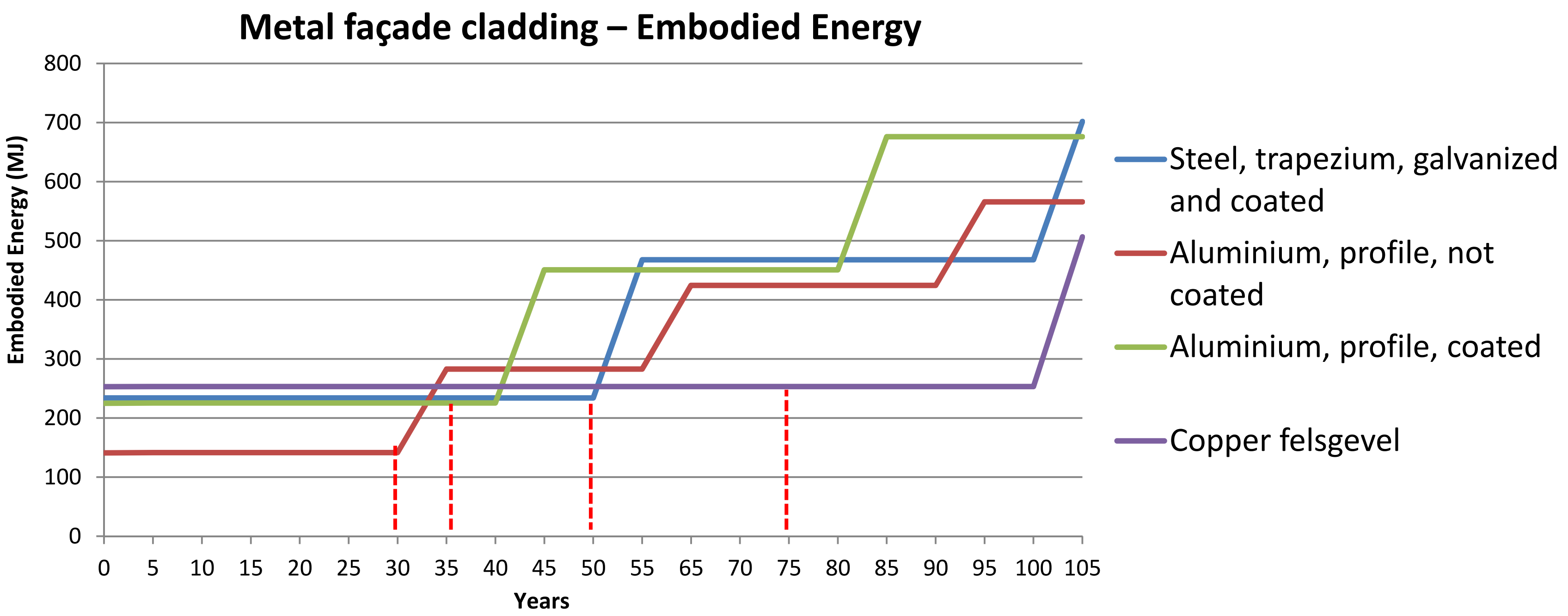
-Embodied energy

-Environmental costs

(-Building costs)

-Data from NIBE database

-For life spans from 15-200 years

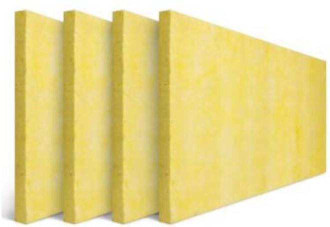


Façade analysis – Materials

Sub research question – Best materials

*5. **What materials can best be used** in the façade (for refurbishment) to lower the environmental impact, with a focus on the embodied energy?*

For 35 years:



Cavity insulation:
Glasswool

Roof insulation:
EPS plates

Inside cavity wall:
Timber frame

Outside cavity wall:
Mud brick

Timber cladding:
Oak

Stone cladding:
Fibre cement

Window frame:
European softwood

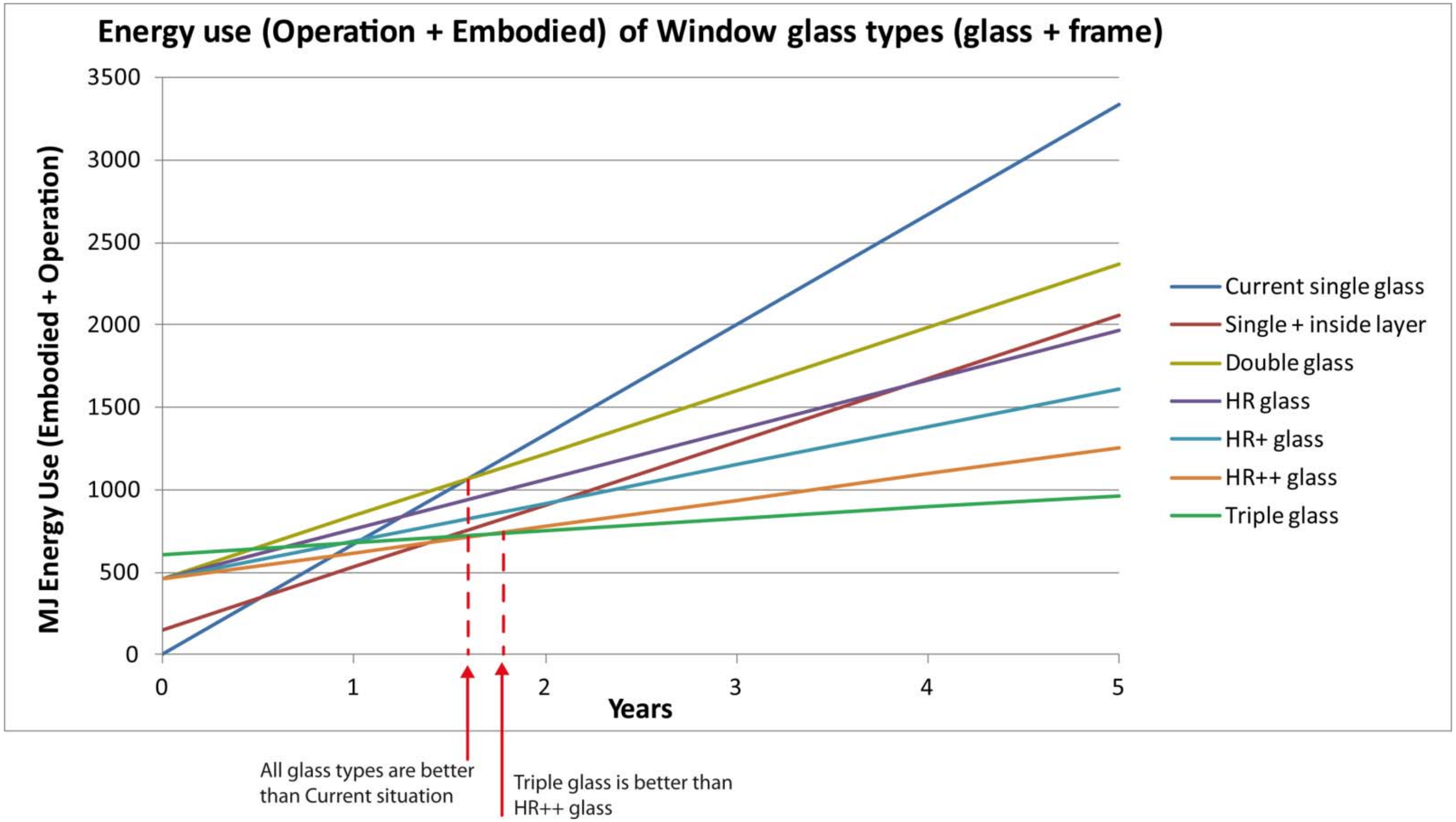
Door:
Tropical multiplex

Façade analysis – Materials

Glass – Energy use

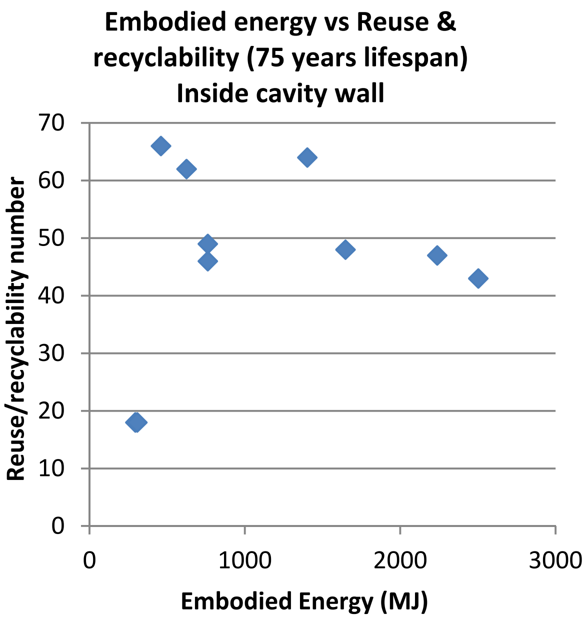
-Operation Energy needed for transmission losses + Solar energy gain (MJ)

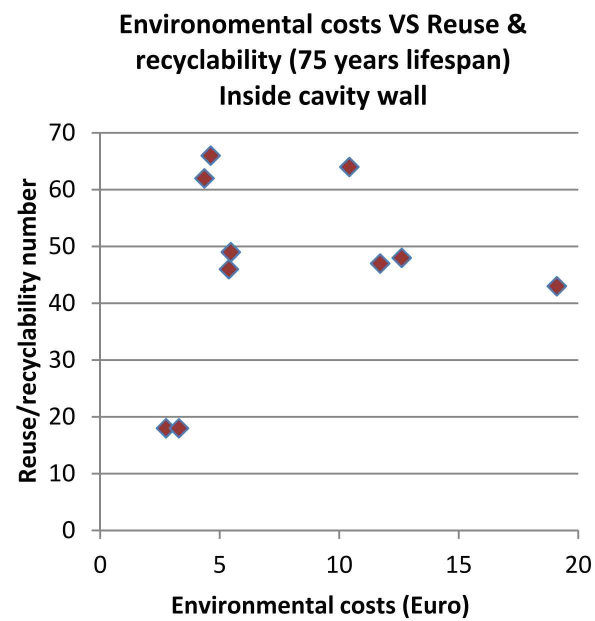
-Embodied energy (MJ)



Sub research question

*6. How can **reusing and recycling of (façade) materials** contribute to lower the environmental impact, with a focus on the embodied energy?*





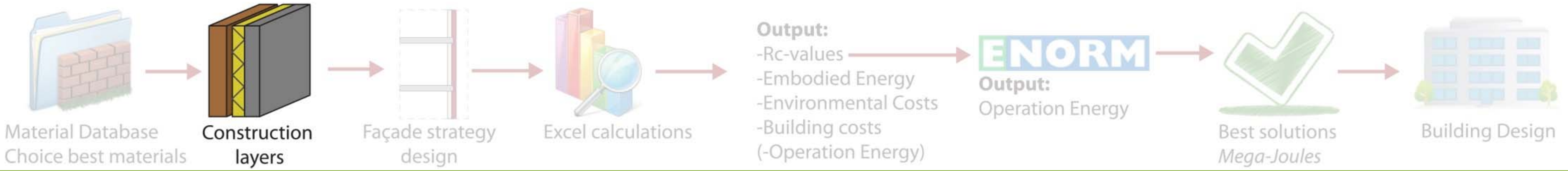
-No linear relationship between Recyclability and Embodied Energy

-Extra reuse/recycleability per material needs to be assessed, after use

-Reusing existing single glazing in balustrade: 4.4% Embodied Energy savings

Façade analysis - Construction

Façade design approach – Construction layers



-R-values of all layers → Rc-value

-Total Embodied Energy

Name Constr	Outside Airflow	R-Value	Layer 1	λ	R-value	Thicknes	EBE
New sandwich panel 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New window sill 2	Outside Airflow	0,04	Pinewood (renwably grown)	0,200	0,5700	0,1140	525,78
New outside window frame 2	Outside Airflow	0,04	European Hardwood (renew.	0,274	0,4167	0,1140	400,22
New inside window frame 2	Outside Airflow	0,04	European Hardwood (renew.	0,274	0,2705	0,0740	259,79
New closed balcony 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New glass 2	Outside Airflow	0,04	Tripple glass	0,700	1,4286	1,0000	449,40
New suskast ventilation 2	Outside Airflow	0,04	Suskast	1,088	0,3125	0,3400	0,00
New thick window frame 2	Outside Airflow	0,04	Wooden frame 15% of wall	0,200	0,9000	0,1800	379,74
New balcony roof 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New side balcony 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New plate material 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New roof insulation + floor 2	Outside Airflow	0,04	EPS plates	0,034	5,0000	0,1715	313,25
New masonry 2	Outside Airflow	0,04	Mud brick masonry (incl. plas	0,930	0,1505	0,1400	569,71
New extra thick window frame 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New closed balcony bottom 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New concrete edge wall 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New upper concrete edge 2	Outside Airflow	0,04	Oak (renewably grown)	0,000	0,0000	0,0160	35,99
New linear cold bridge concrete 2	Outside Airflow	0,04	Fibre cement plate	0,000	0,0000	0,0100	221,77
New linear cold bridge masonry 2	Outside Airflow	0,04	Mud brick masonry (incl. plas	0,930	0,1505	0,1400	569,71

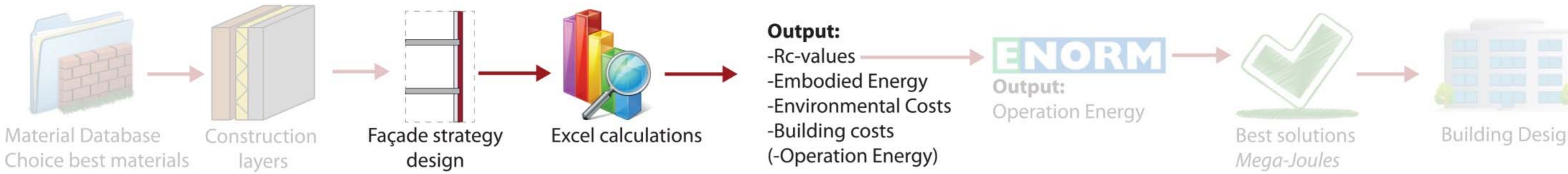
Name Constr	Layer 2	λ	R-value	Thickness	EBE	Layer 3	λ	R-value	Thicknes	EBE
New sandwich panel 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Grindbeton old	1,600	0,050	0,0800	0,00
New window sill 2	Grindbeton old	1,600	0,063	0,1000	0,00	Polystyrene old	0,080	0,125	0,0100	0,00
New outside window frame 2										
New inside window frame 2										
New closed balcony 2	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + wooden	0,060	3,5000	0,2091	174,54
New glass 2										
New suskast ventilation 2										
New thick window frame 2										
New balcony roof 2	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	EPS plates	0,034	3,5000	0,1201	219,27
New side balcony 2	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + wooden	0,060	3,5000	0,2091	174,54
New plate material 2	Glaswool plates + wooden	0,060	3,5000	0,2091	174,54	Plate old	0,200	0,040	0,0080	0,00
New roof insulation + floor 2	Polystyrene old	0,080	0,313	0,0250	0,00	Grindbeton old	1,600	0,088	0,1400	0,00
New masonry 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Masonry old	0,781	0,134	0,1050	0,00
New extra thick window frame 2	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + wooden	0,060	3,5000	0,2091	174,54
New closed balcony bottom 2	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + wooden	0,060	3,5000	0,2091	174,54
New concrete edge wall 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Grindbeton old	1,600	0,050	0,0800	0,00
New upper concrete edge 2	Stronly ventilated cavity	0,000	0,0000	0,0500	0,00	Glaswool plates + wooden	0,060	3,5000	0,2091	174,54
New linear cold bridge concrete 2	Glaswol platen	0,035	3,5000	0,1225	82,99					
New linear cold bridge masonry 2	Glaswol platen	0,035	3,5000	0,1225	82,99	Masonry old	0,781	0,134	0,1050	0,00

Name Constr	Layer 4	λ	R-value	Thicknes	EBE	Layer 5	λ	R-value	Thickness	EBE	Inside Airflow	R-Value	Rc-value	U-Value	Total EBE
New sandwich panel 2	Polystyrene old	0,080	0,125	0,0100	0,00	Gasbeton old	0,220	0,273	0,0600	0	Inside Airflow	0,13	**4,12**	**0,24**	304,76
New window sill 2	Grindbeton old	1,600	0,038	0,0600	0						Inside Airflow	0,13	**0,97**	**1,04**	525,78
New outside window frame 2											Inside Airflow	0,13	**0,59**	**1,70**	400,22
New inside window frame 2											Inside Airflow	0,13	**0,44**	**2,27**	259,79
New closed balcony 2											Inside Airflow	0,13	**3,67**	**0,27**	210,53
New glass 2											Inside Airflow	0,13	**1,60**	**0,63**	449,40
New suskast ventilation 2											Inside Airflow	0,13	**0,48**	**2,07**	0,00
New thick window frame 2											Inside Airflow	0,13	**1,07**	**0,93**	379,74
New balcony roof 2											Inside Airflow	0,13	**3,67**	**0,27**	441,04
New side balcony 2											Inside Airflow	0,13	**3,67**	**0,27**	210,53
New plate material 2	Weakly ventilated c	0,000	0,090	0,0800	0,00	Plate old	0,200	0,040	0,0080	0	Inside Airflow	0,13	**3,84**	**0,26**	210,53
New roof insulation + floor 2											Inside Airflow	0,13	**5,57**	**0,18**	313,25
New masonry 2	Weakly ventilated c	0,000	0,090	0,1650	0,00	Grindbeton old	0,625	0,320	0,2000	0	Inside Airflow	0,13	**4,36**	**0,23**	652,71
New extra thick window frame 2	Hardwood old	0,200	0,860	0,1720	0,00						Inside Airflow	0,13	**4,53**	**0,22**	35,99
New closed balcony bottom 2	Grindbeton old	1,600	0,094	0,1500	0,00						Inside Airflow	0,13	**3,76**	**0,27**	35,99
New concrete edge wall 2	Polystyrene old	0,080	0,125	0,0100	0,00	Gasbeton old	0,220	0,273	0,0600	0	Inside Airflow	0,13	**4,12**	**0,24**	304,76
New upper concrete edge 2	Grindbeton old	1,600	0,094	0,1500	0,00						Inside Airflow	0,13	**3,76**	**0,27**	35,99
New linear cold bridge concrete 2											Inside Airflow	0,13	**3,67**	**0,27**	304,76
New linear cold bridge masonry 2	Weakly ventilated c	0,000	0,090	0,1650	0,00	Grindbeton old	0,625	0,320	0,2000	0	Inside Airflow	0,13	**4,36**	**0,23**	652,71

Construction — Layer 1 — Layer 2 — Layer 3 — Layer 4 — Layer 5 — Total Rc Total E.E.

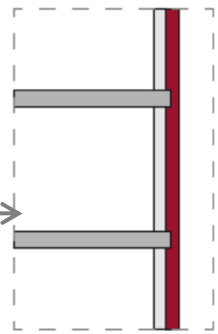
Façade analysis – Strategies

Façade design approach – Façade strategies & excel calculation

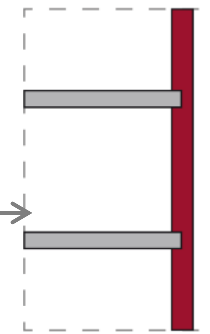


-Extra insulation Rfacade = 3.5m2K/W and Rroof = 5m2K/W

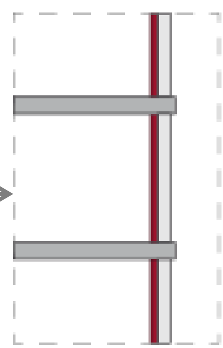
1. Exterior Upgrading



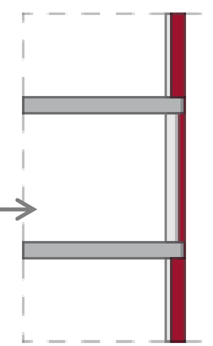
2. Complete façade replacement



3. Interior upgrading



4. Partial replacement, partial exterior upgrading (Portaal)



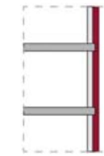
Façade analysis – Strategies

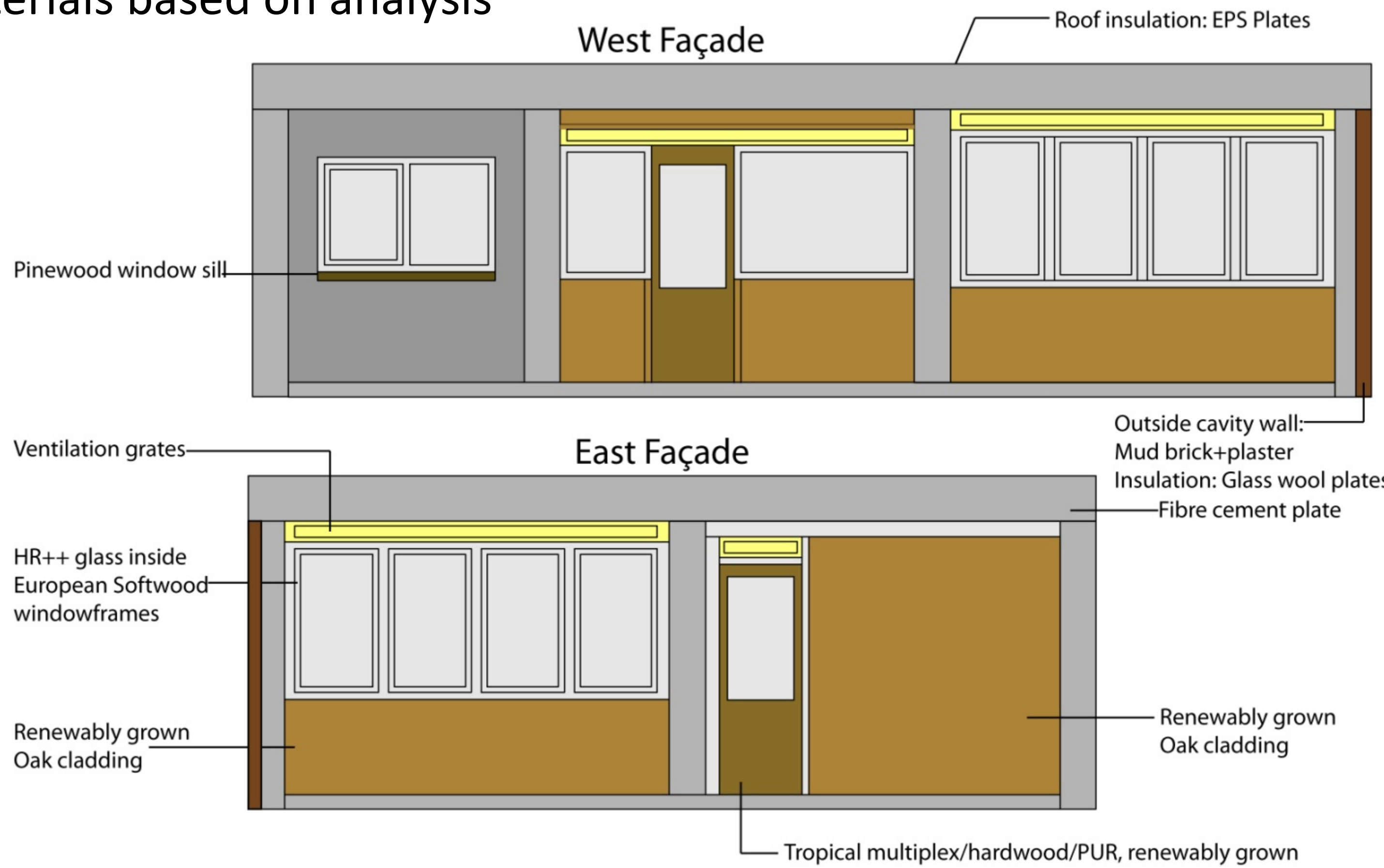
Materials for Strategy designs

-Top right apartment of building

-Based on the design of Portaal

-Materials based on analysis

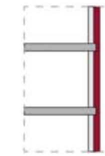


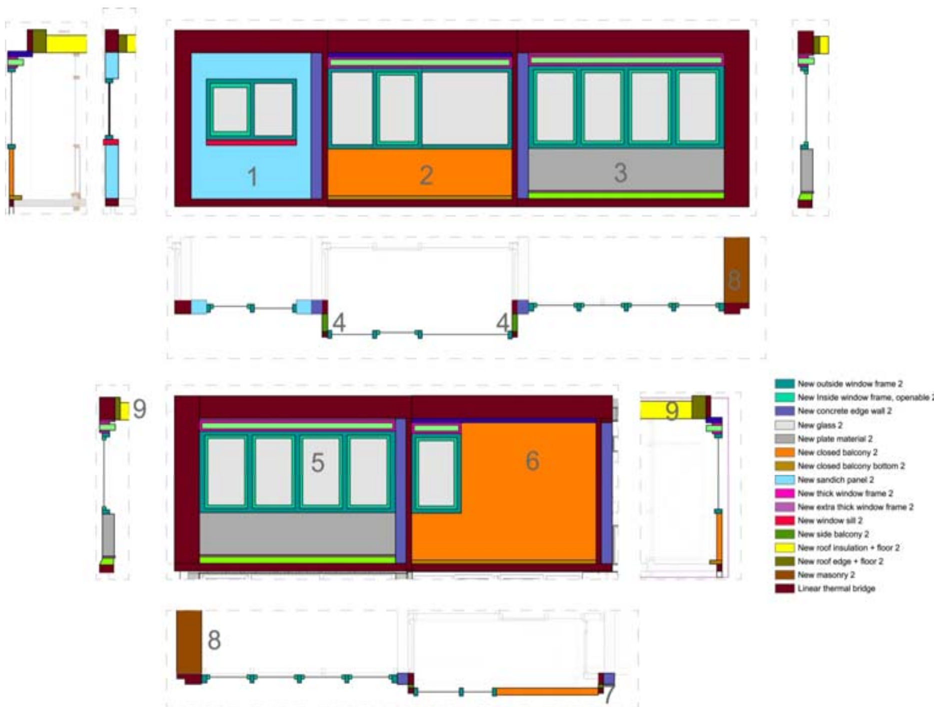


Strategies – Excel calculations

-Simplified designs

-Removal of old materials: Remaining Embodied Energy material = 1/3 initial, the rest can be 'written off'





Facade part — Construction — Properties — Embodied Energy / Building Costs / Environmental costs

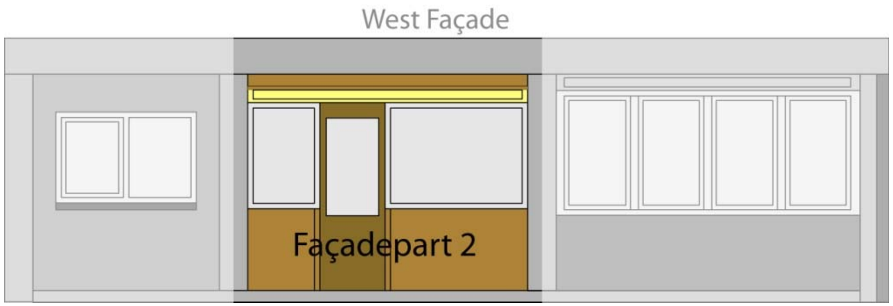
WEST FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)	Building costs (Euro)	Environmental costs (Euro)	Embodied energy (MJ) removal old
Facadepart 1.1	New sandwich panel 2	4,03	4,12	1228,20	211,83	8,70	
Facadepart 1.2	New concrete edge wall 2	0,56	4,12	170,55	29,41	1,21	
Facadepart 1.3	New window sill 2	0,17	0,97	86,75	76,00	0,67	62
Facadepart 1.4	New outside window frame 2	0,48	0,59	191,42	367,65	1,64	
Facadepart 1.5	New inside window frame 2	0,20	0,44	53,10	101,99	0,46	
Facadepart 1.6	New glass 2	1,21	1,60	545,66	97,68	0,00	
Facadepart 2.1	New closed balcony 2	3,03	3,67	637,86	189,10	6,09	
Façadepart 2.2	New balcony roof 2	0,28	3,67	122,04	16,14	0,69	
Facadepart 2.3	New thick window frame 2	0,31	1,07	118,93	25,37	1,11	
Facadepart 2.4	New closed balcony bottom 2	0,25	3,76	8,87	15,38	0,50	216
Facadepart 2.5	New suskast ventilation 2	0,38	0,48	0,00	0,00	0,00	
Facadepart 2.6	New outside window frame 2	0,94	0,59	374,32	718,92	3,21	
Facadepart 2.7	New inside window frame 2	0,22	0,44	57,54	110,52	0,49	
Facadepart 2.8	New glass 2	4,01	1,60	1802,72	322,72	0,00	
Facadepart 3.1	New plate material 2	2,89	3,84	608,34	180,35	5,81	
Facadepart 3.2	New extra thick window frame 2	0,25	4,53	9,06	15,72	0,51	
Facadepart 3.3	New upper concrete edge 2	0,43	3,76	15,37	26,65	0,86	
Facadepart 3.4	New thick window frame 2	0,35	1,07	131,31	28,01	1,22	
Facadepart 3.5	New suskast ventilation 2	0,41	0,48	0,00	0,00	0,00	210
Facadepart 3.6	New concrete edge wall 2	0,56	4,12	169,69	29,27	1,20	
Facadepart 3.7	New outside window frame 2	1,23	0,59	492,15	945,22	4,22	
Facadepart 3.8	New inside window frame 2	0,91	0,44	235,34	452,00	2,02	
Facadepart 3.9	New glass 2	3,47	1,60	1561,35	279,51	0,00	
WEST BALCONY SIDES		Surface (m2)	Rcvalue	Embodied Energy (MJ)			E.E. removal old
Facadepart 4.1	New side balcony 2	1,73	3,67	363,58	107,79	3,47	0
EAST FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)			E.E. removal old
Facadepart 5.1	New plate material 2	2,90	3,84	611,06	181,15	5,84	
Facadepart 5.2	New extra thick window frame 2	0,25	4,53	9,05	15,70	0,51	
Facadepart 5.3	New upper concrete edge 2	0,46	3,76	16,63	28,84	0,93	
Facadepart 5.4	New thick window frame 2	0,34	1,07	130,36	27,81	1,21	
Facadepart 5.5	New suskast ventilation 2	0,41	0,48	0,00	0,00	0,00	210
Facadepart 5.6	New concrete edge wall 2	0,54	4,12	165,18	28,49	1,17	
Facadepart 5.7	New outside window frame 2	1,24	0,59	495,55	951,75	4,25	
Facadepart 5.8	New inside window frame 2	0,90	0,44	233,23	447,93	2,00	
Facadepart 5.9	New glass 2	3,47	1,60	1561,35	279,51	0,00	
Facadepart 6.1	New closed balcony 2	7,33	3,67	1542,50	457,29	14,74	
Facadepart 6.2	New balcony roof 2	0,27	3,67	116,88	15,46	0,66	
Facadepart 6.3	New thick window frame 2	0,10	1,07	36,11	7,70	0,34	
Facadepart 6.4	New suskast ventilation 2	0,10	0,48	0,00	0,00	0,00	
Facadepart 6.5	New concrete edge wall 2	0,56	4,12	170,97	29,49	1,21	0
Facadepart 6.6	New closed balcony bottom 2	0,25	3,76	8,87	15,38	0,50	
Facadepart 6.7	New outside window frame 2	0,35	0,59	139,16	267,26	1,19	
Facadepart 6.8	New inside window frame 2	0,22	0,44	57,54	110,52	0,49	
Facadepart 6.9	New glass 2	0,82	1,60	367,83	65,85	0,00	
EAST SIDE WALL		Surface (m2)	Rcvalue	Embodied Energy (MJ)			E.E. removal old
Facadepart 7.1	New side balcony 2	0,33	3,67	70,00	20,75	0,67	0
SOUTH FAÇADE		Surface (m2)	Rcvalue	Embodied Energy (MJ)			E.E. removal old
Facadepart 8.1	New masonry 2	25,31	4,36	16518,04	284,18	132,51	0
ROOF		Surface (m2)	Rcvalue	Embodied Energy (MJ)			E.E. removal old
Facadepart 9.1	New roof insulation + floor 2	77,04	5,57	24132,42	1871,75	122,21	0
Linear cold bridge		Surface (m2)		Embodied Energy (MJ)			
Linear cold bridge west 1	New linear cold bridge concrete 2	2,74	-	835,05	144,02	5,92	
Linear cold bridge west 2	New linear cold bridge concrete 2	1,93	-	588,19	101,45	4,17	
Linear cold bridge west 3	New linear cold bridge concrete 2	4,07	-	1238,86	213,67	8,78	
Linear cold bridge east 5	New linear cold bridge concrete 2	3,71	-	1130,67	195,01	8,01	0
Linear cold bridge east 6	New linear cold bridge concrete 2	2,71	-	826,82	142,60	5,86	
Linear cold bridge south conc	New linear cold bridge concrete 2	2,68	-	815,24	140,60	5,78	
Linear cold bridge south maso	New linear cold bridge masonry 2	2,68	-	1745,99	30,04	14,01	

Energy use per façade part

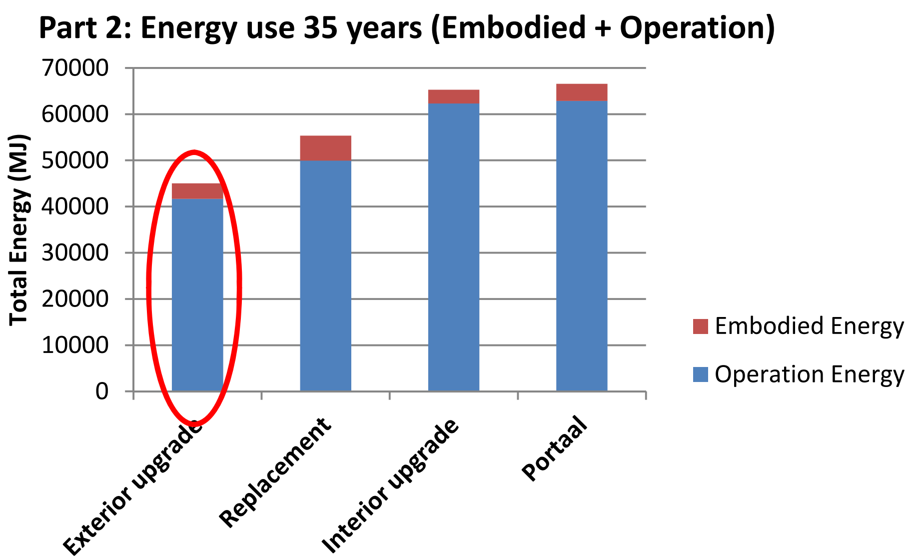
-Per façade part

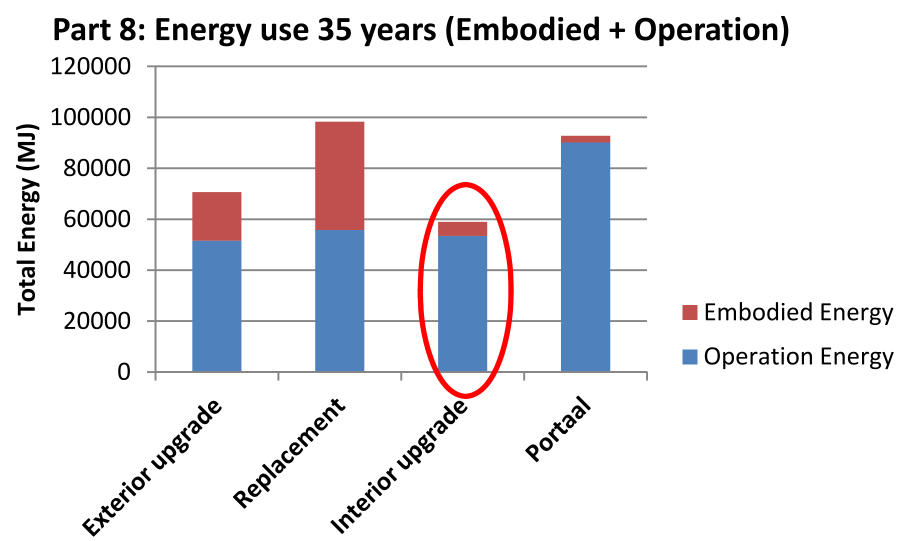
-Hand calculations in Excel

-Operation + Embodied Energy for 35 years



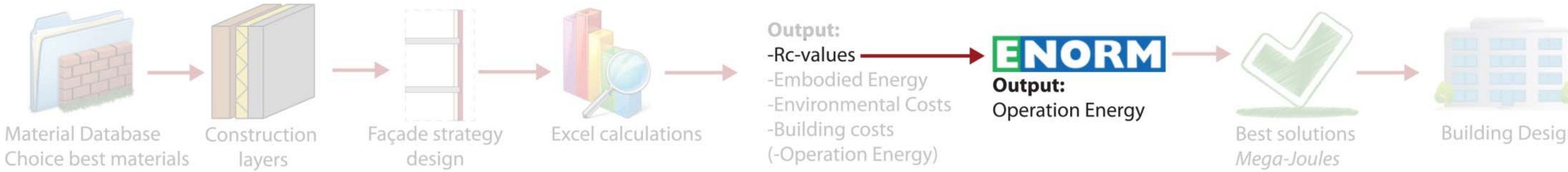
Side façade – masonry, part 8





Façade analysis - EPC

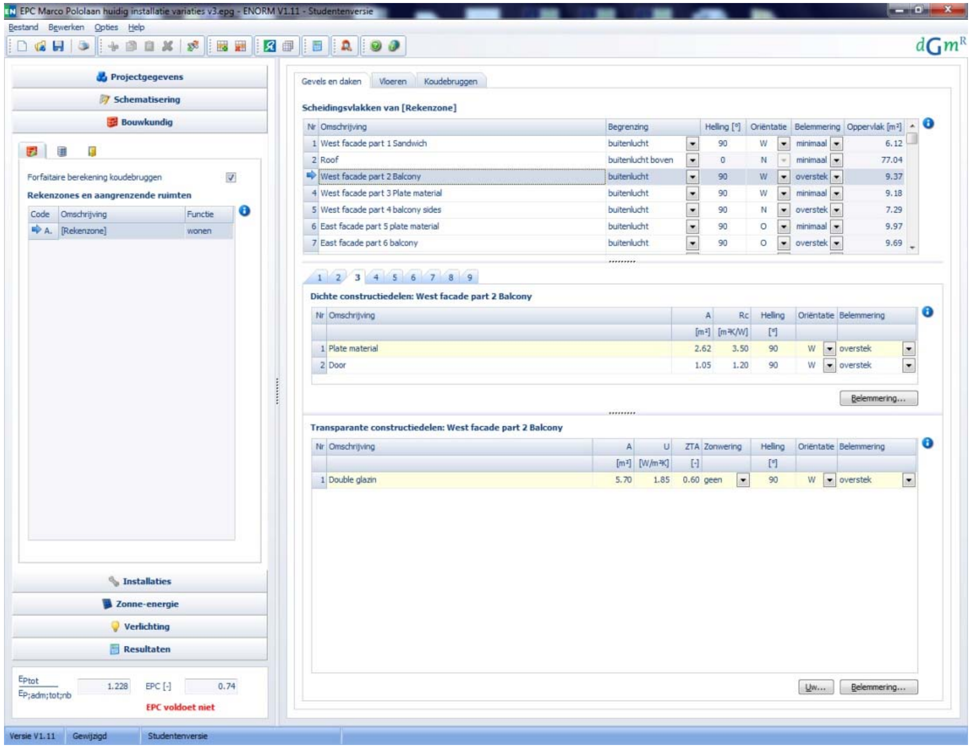
Façade design approach – EPC calculation



-Rc-values and building services

-Gives output: MJ energy use/year

-Heating, cooling, ventilators, humidification, lighting, domestic hot water



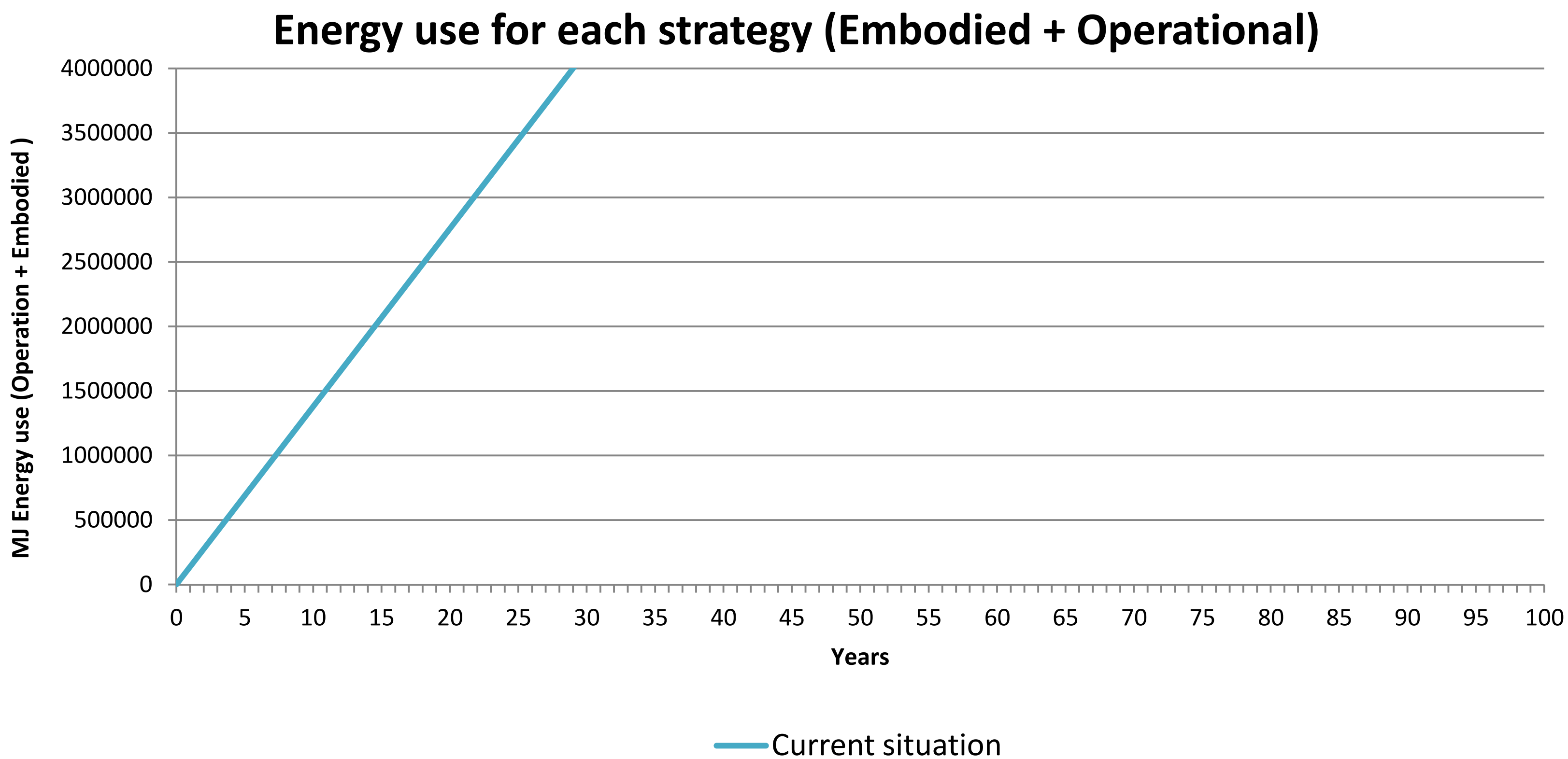
Façade analysis – Conclusions

Energy use for whole apartment

-EPC calculations (Operation Energy)

-Hand calculations (Excel file for Embodied Energy)

-EPC = 0.73-0.77



Façade analysis – Conclusions

Energy use for whole apartment

-EPC calculations (Operation Energy)

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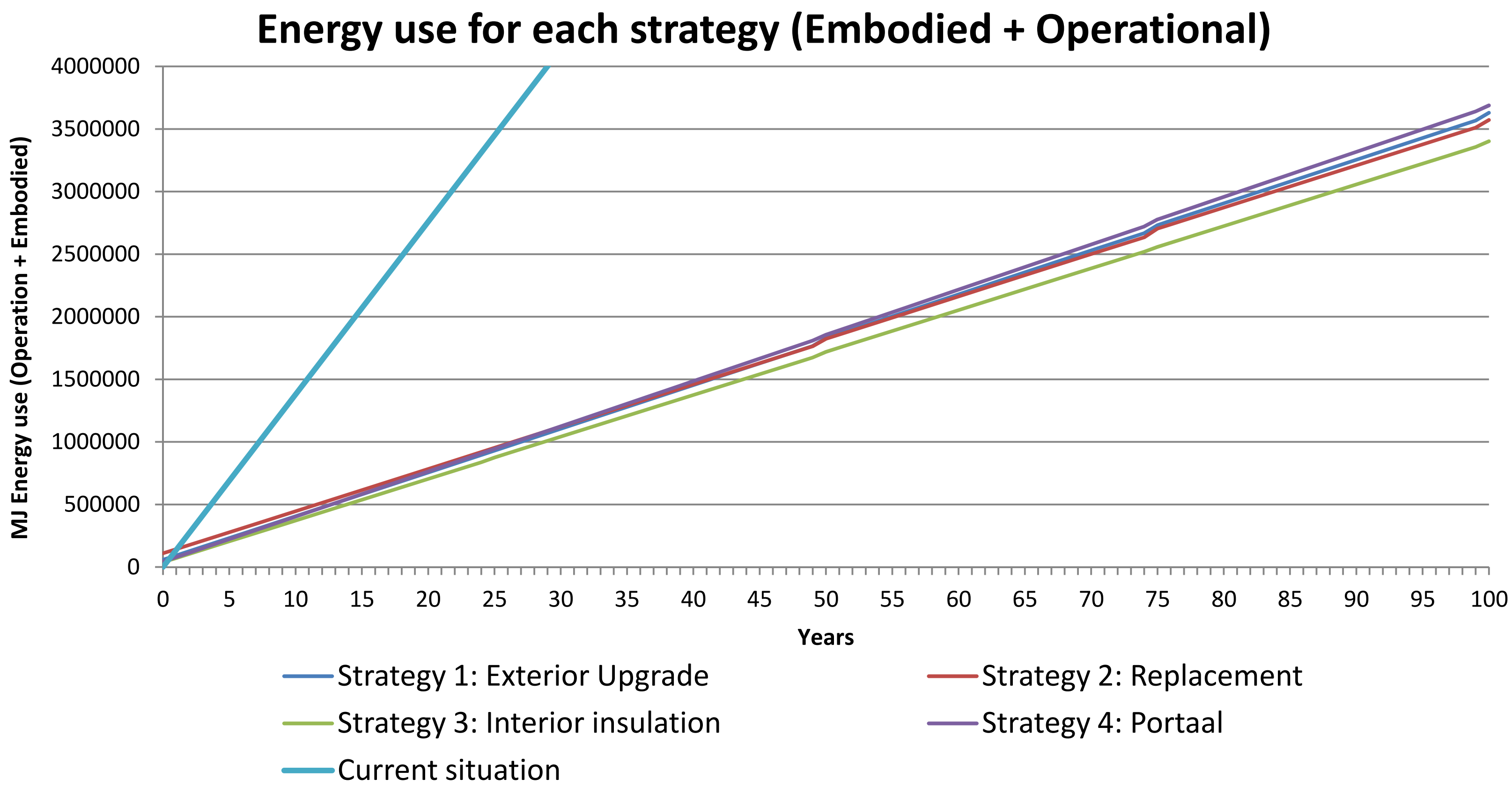
-EPC = 0.73-0.77



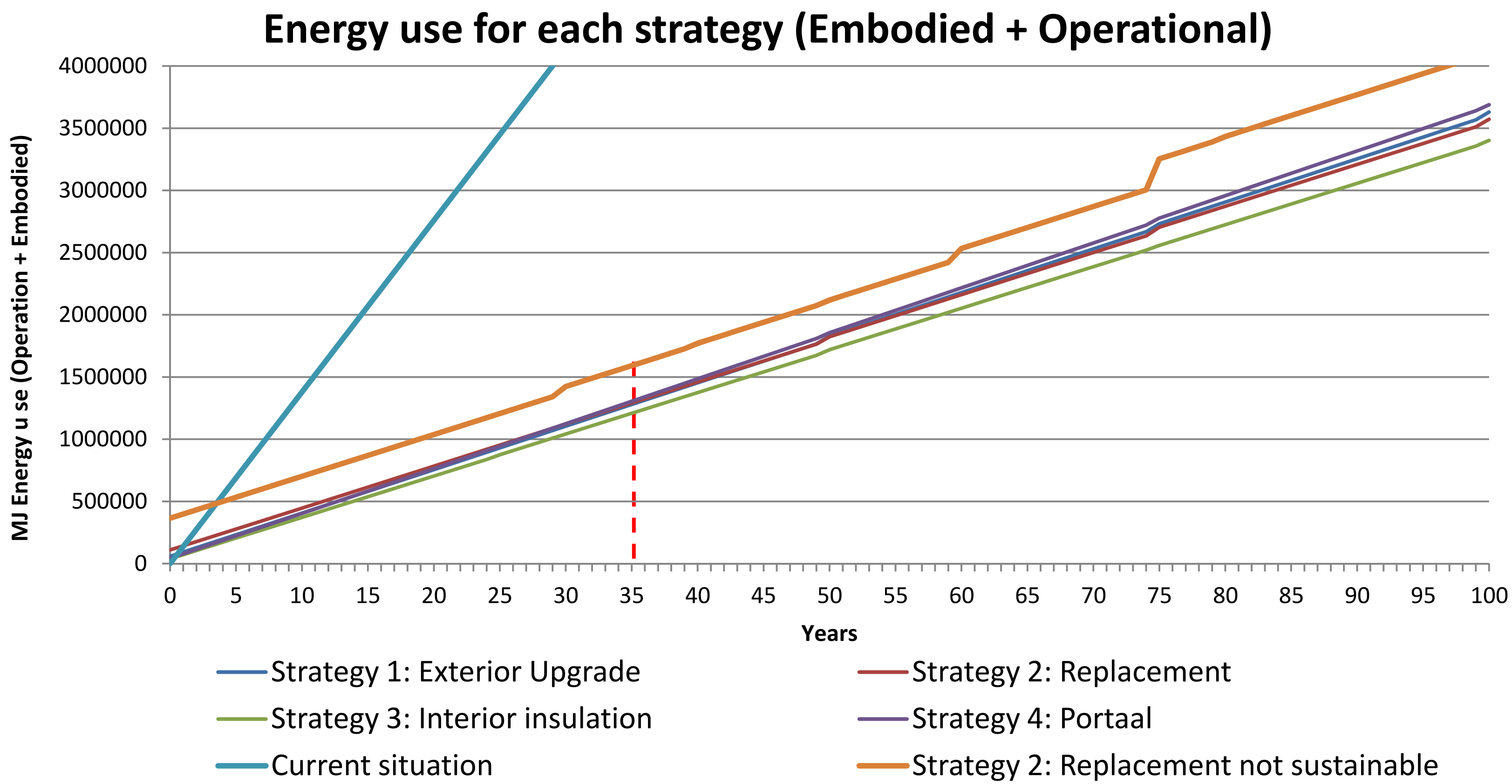
Façade analysis – Conclusions

Energy use for whole apartment

-EPC calculations (Operation Energy)

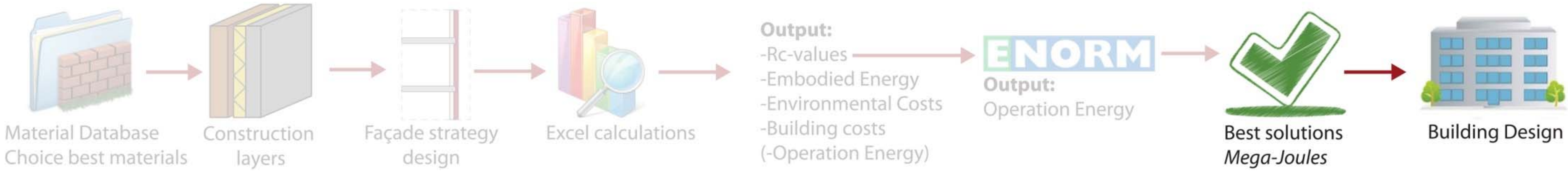
-Hand calculations (Excel file for Embodied Energy)

-EPC = 0.73-0.77

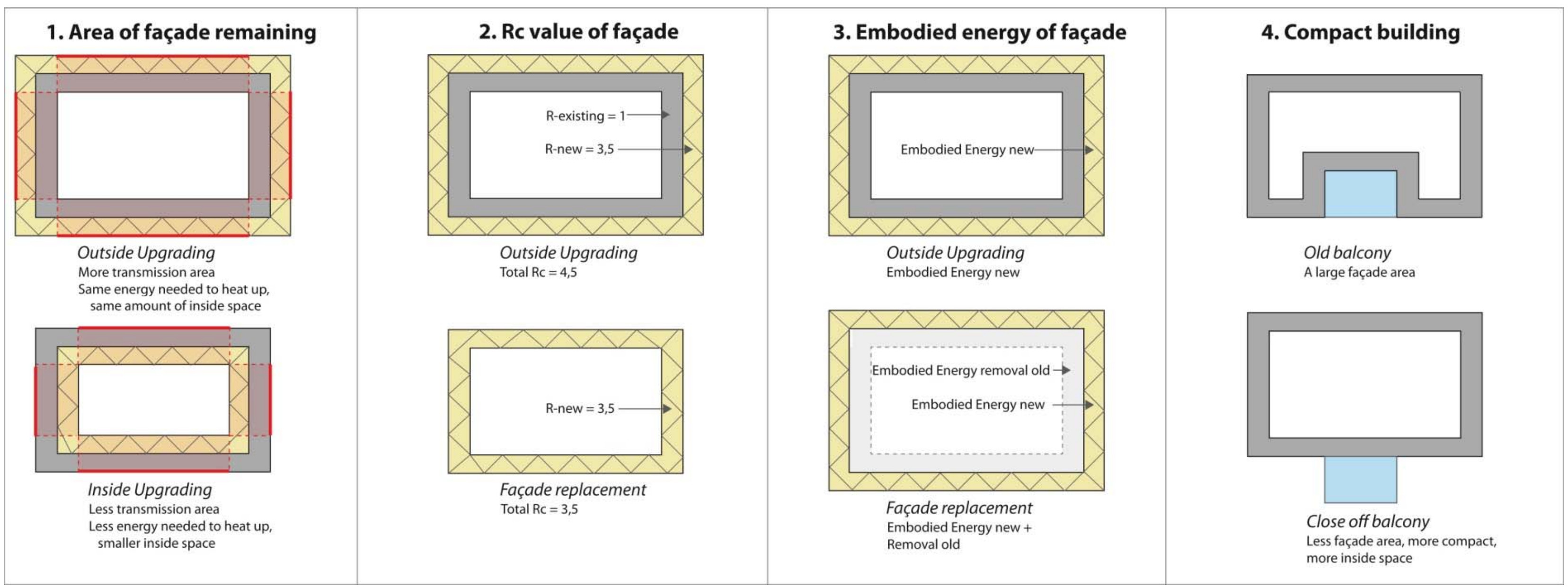


Façade analysis – Conclusions

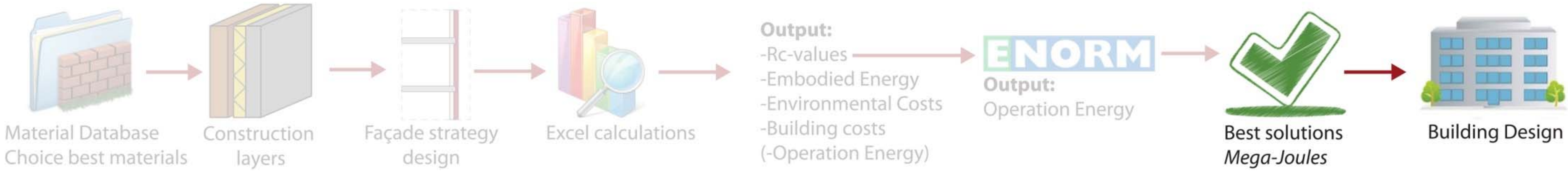
Façade design approach – Conclusions



Conclusions strategies



Façade design approach – Conclusions



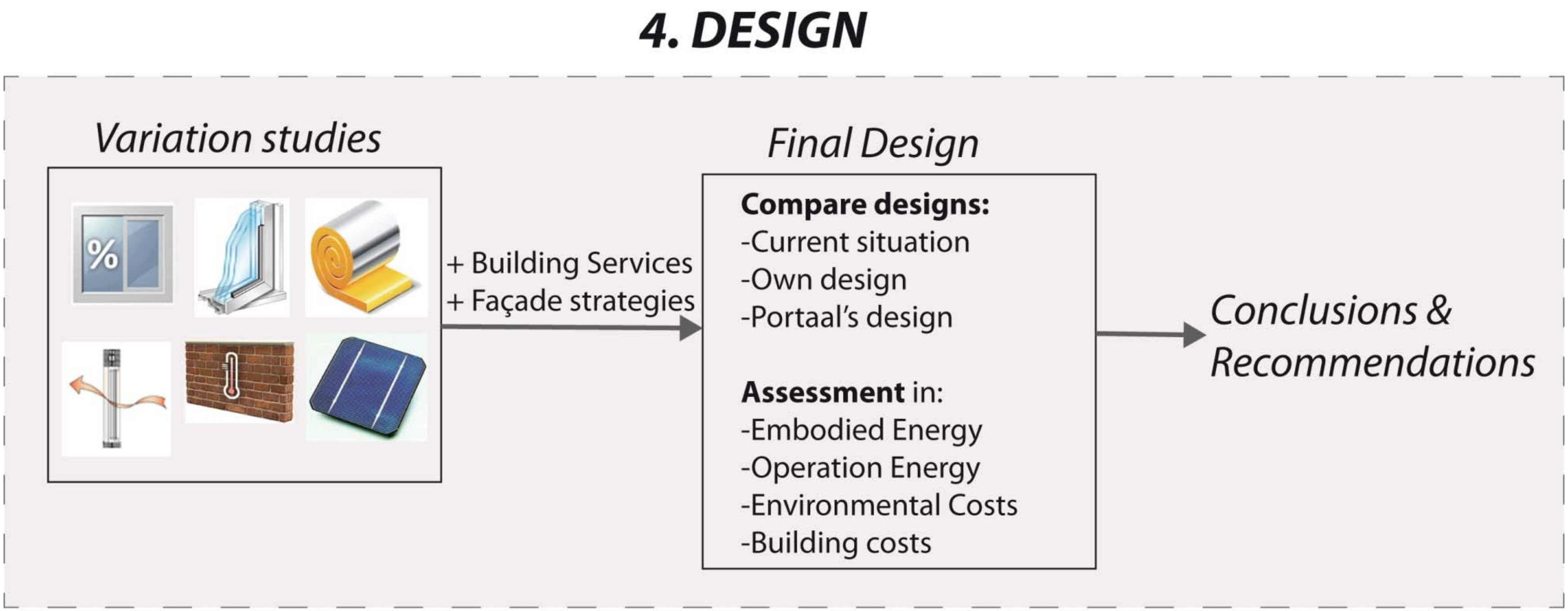
Conclusions for new design

-Addition of external insulation and cladding, keep old

-Masonry on south and north façade kept, cavity insulation and inside insulation

-Closing off old balconies

Design – Approach



Design – Variation studies

Floor plans - parameters

-Area of insulation needed

-Extra new balcony area

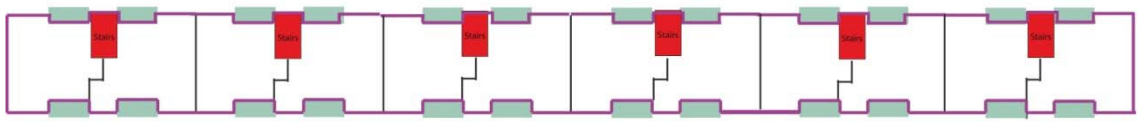
-Cold bridges of balconies

-Area of unheated adjoined rooms

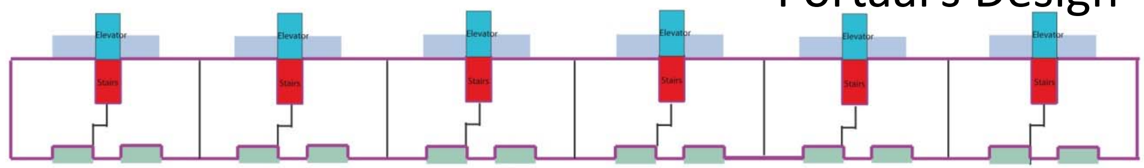
-Energy/costs for elevators

-Inside space area

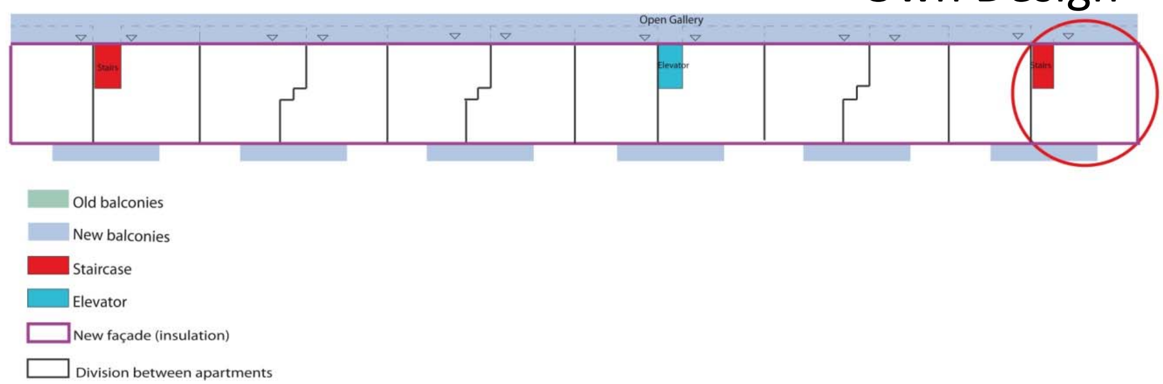
Old situation



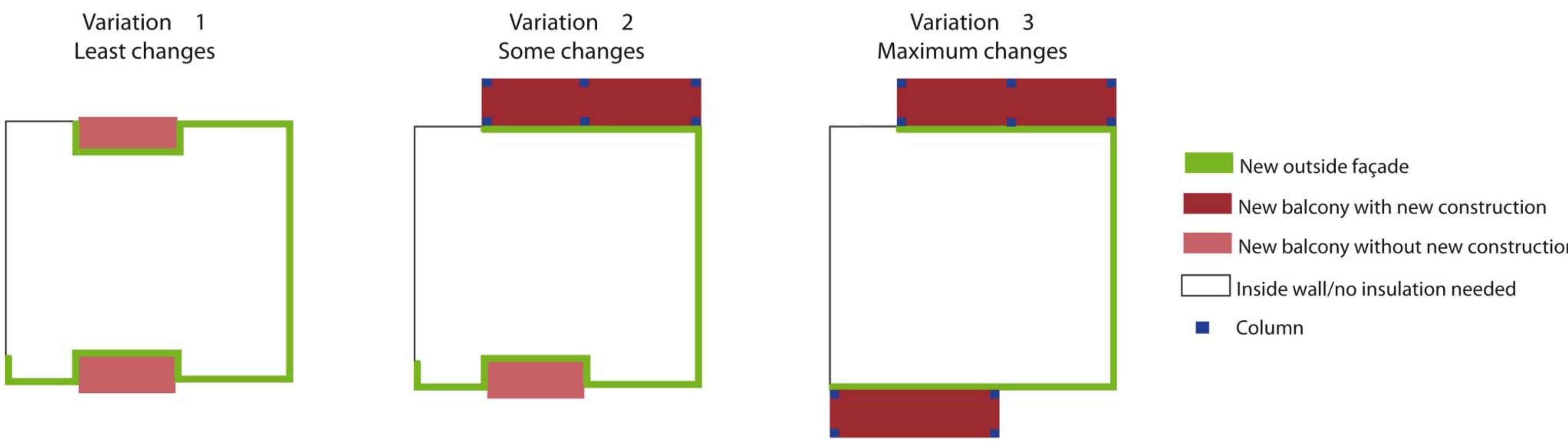
Portaal's Design



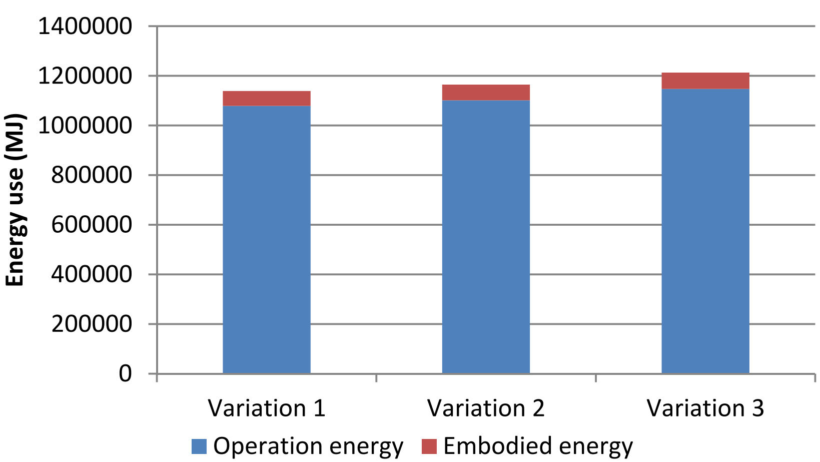
Own Design



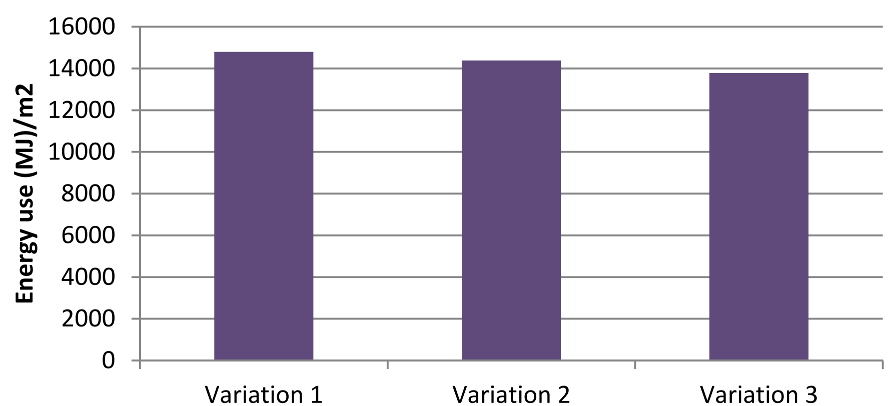
Balconies



Energy use (Operation + Embodied) 35 years



Energy use (Operation + Embodied) 35 years/m2

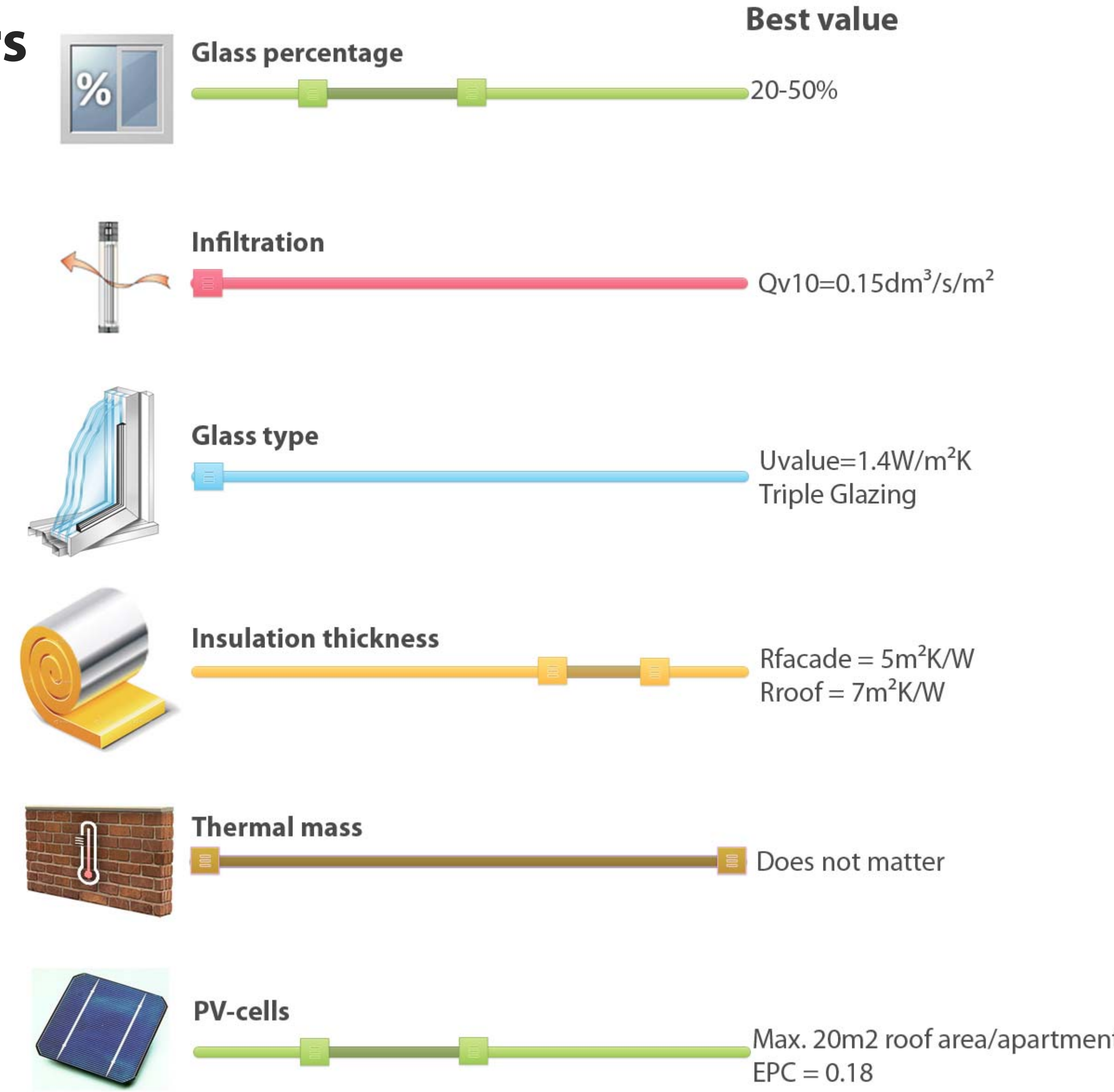


Design – Variation studies

Different parameters

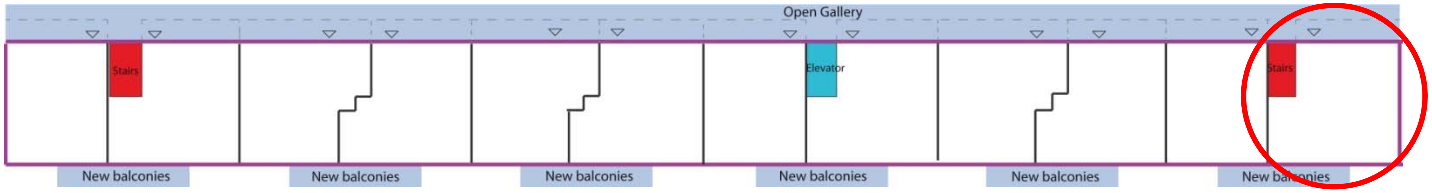
-Calculations in EPC for operation energy

-Excel calculations for embodied energy



Conclusions – For new design

-Gallery balconies, with 2 staircases and 1 elevator



-Closing off old balconies, add new balconies

-Glass percentage 50% or lower

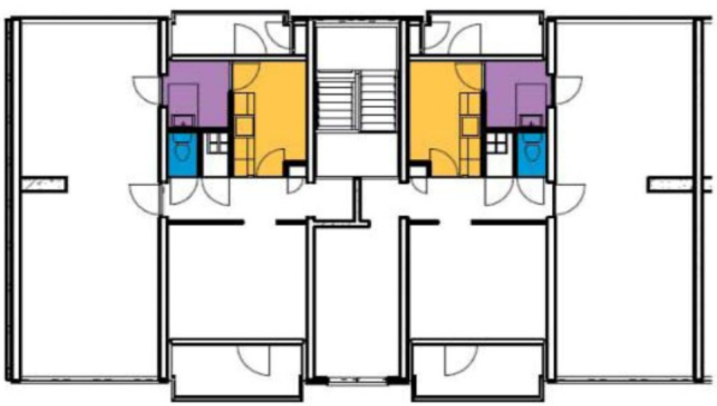
-Extra façade insulation of Rfacade =5 W/m2K Rroof = 7 m2K/W

-Triple glazing

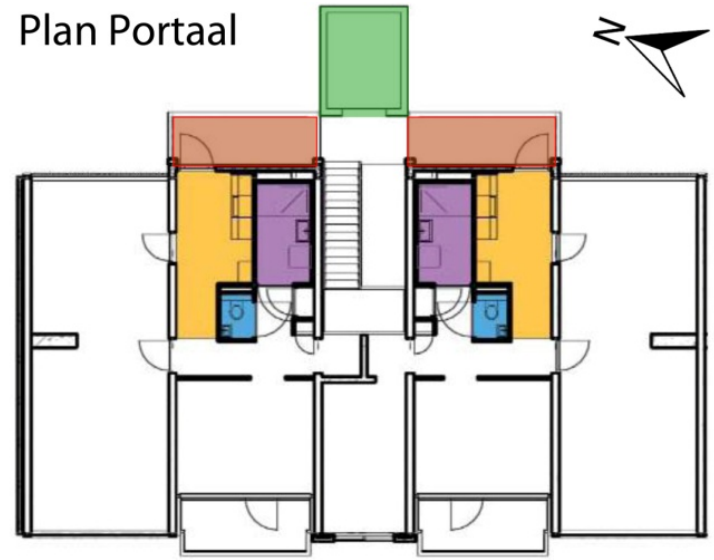
-Infiltration Qv10=0.15dm3/s/m2

Design – Floor plan

Current situation



Plan Portaal

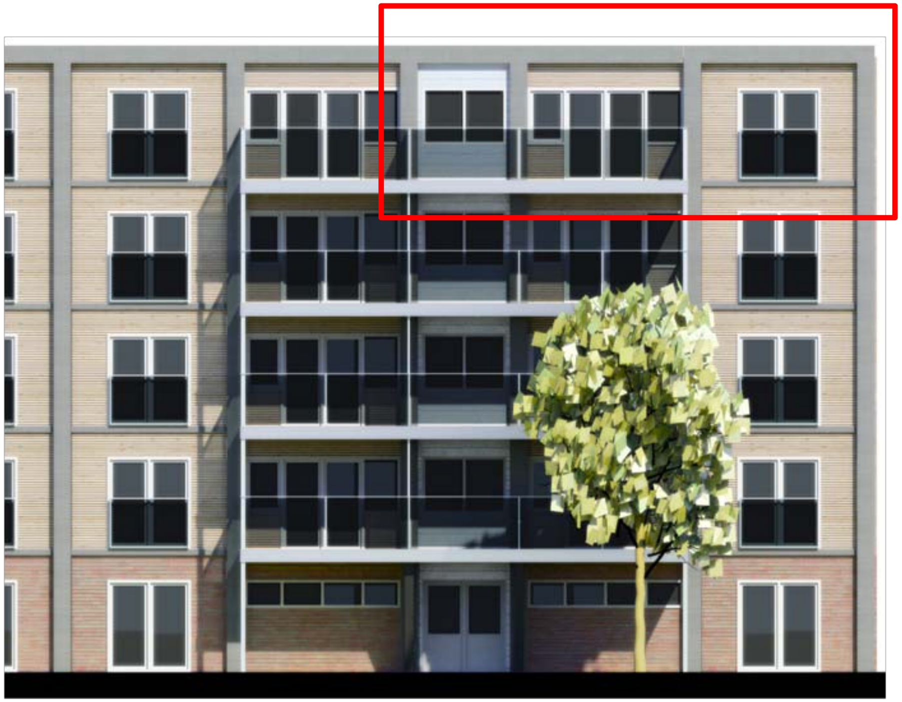


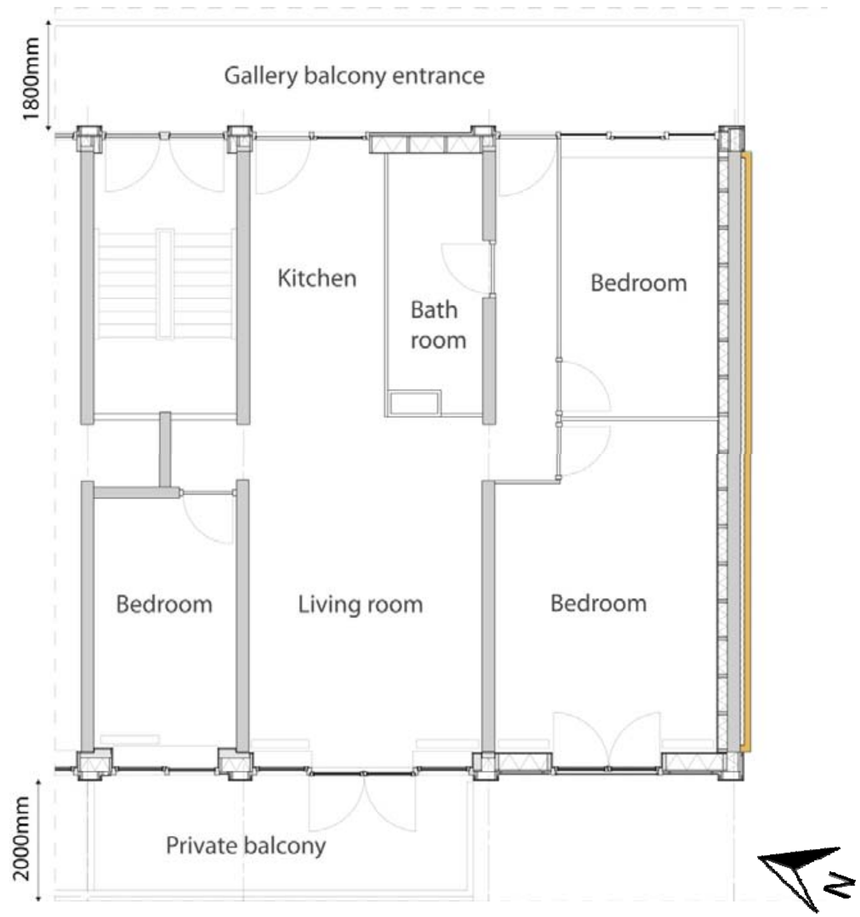
- Bathroom
- Toilet
- Kitchen
- Balcony
- Elevator

Source: Portaal

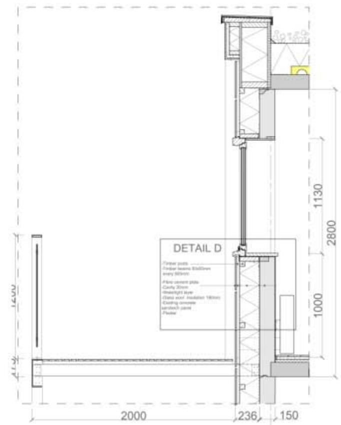
Design – Floor plan

New Design

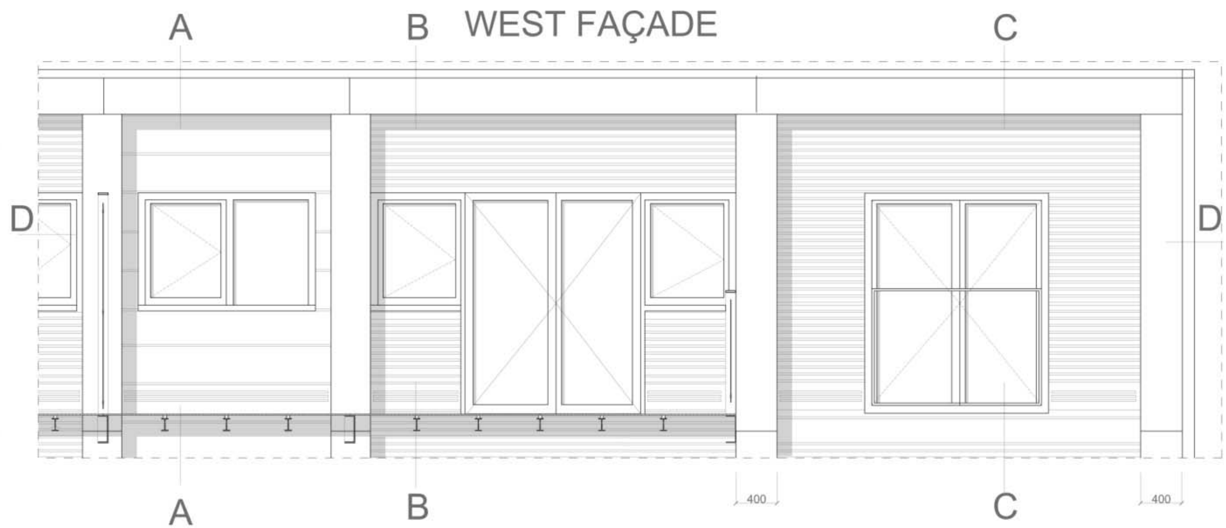


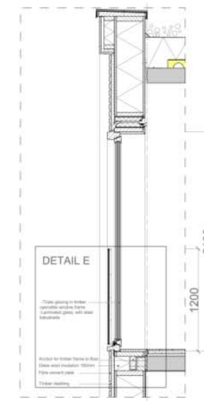


Design – West façade

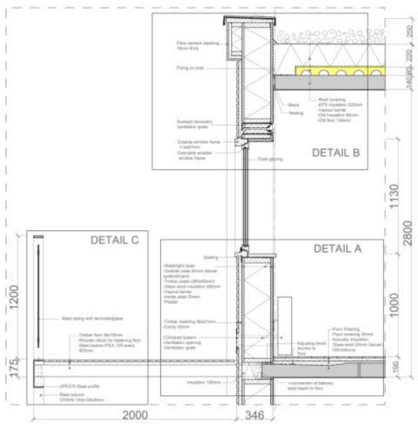


Section A-A

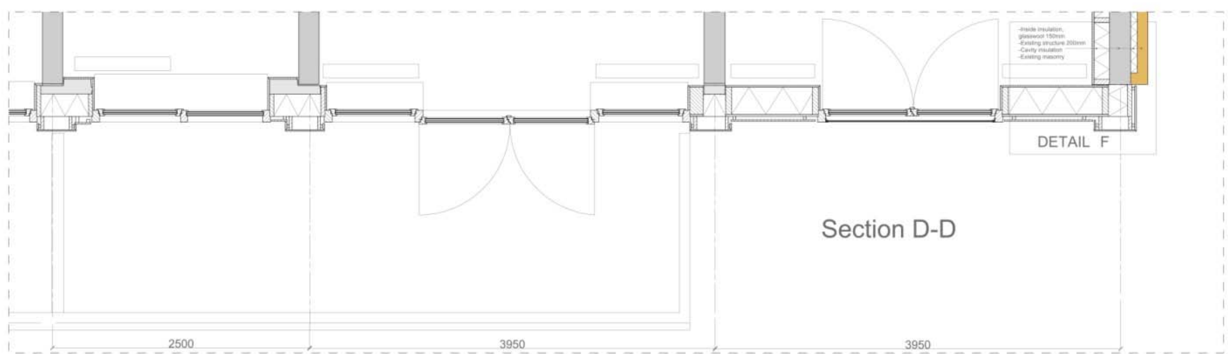




Section C-C



Section B-B



Section D-D

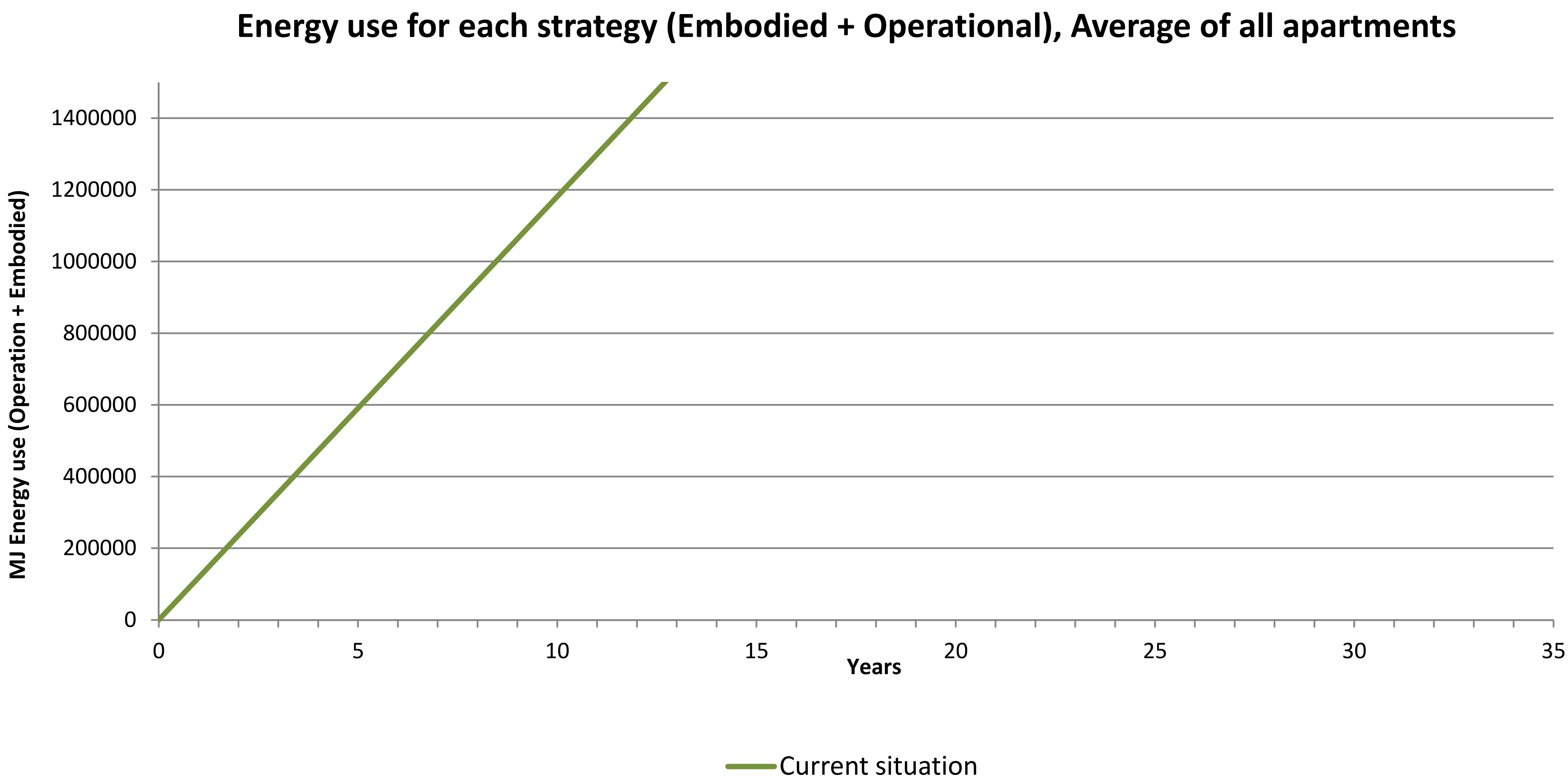
Design – West façade

Design – East façade

Design – Comparison

Energy use 35 years

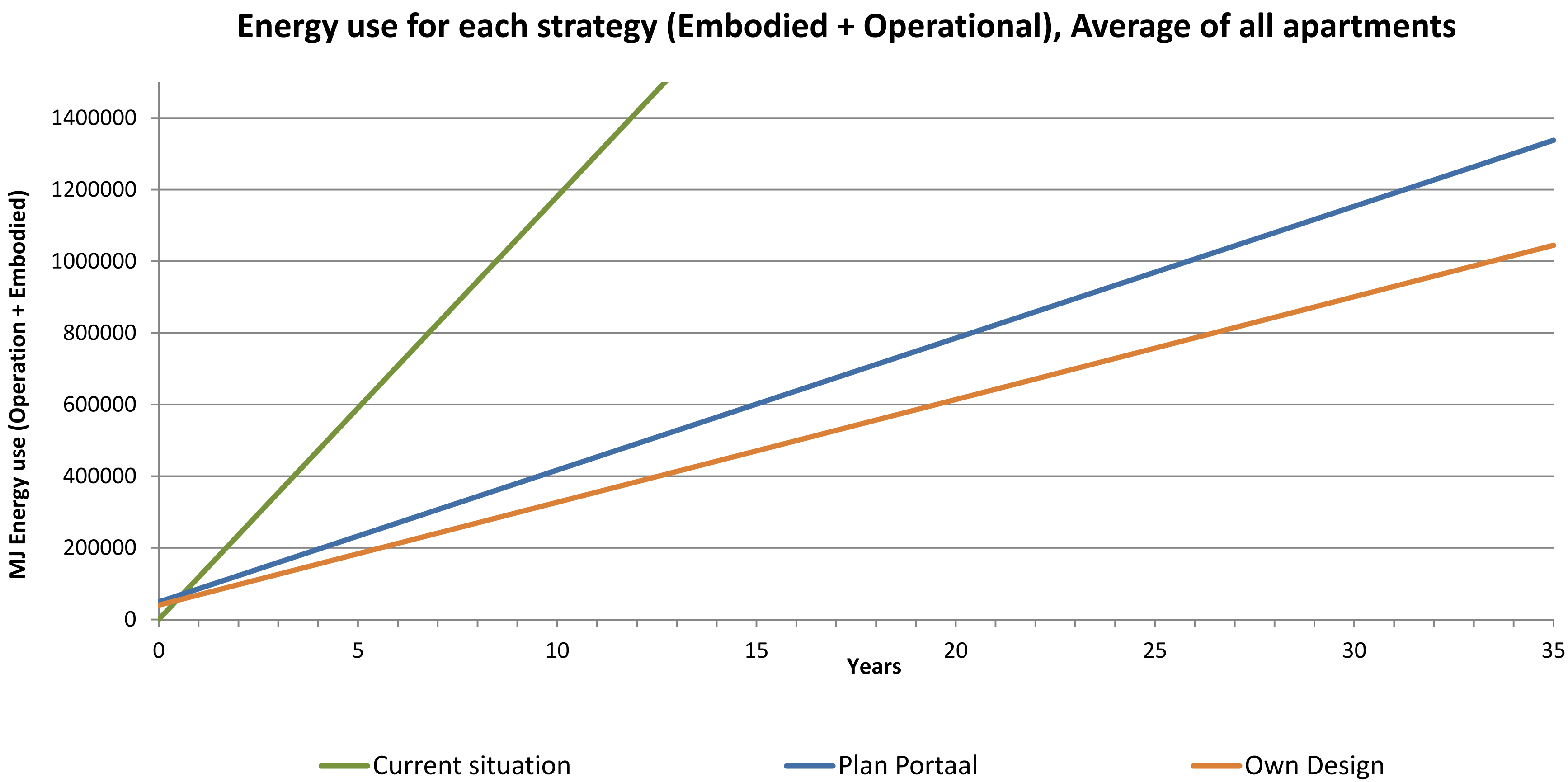
Weighted average of all apartment types



Design – Comparison

Energy use 35 years

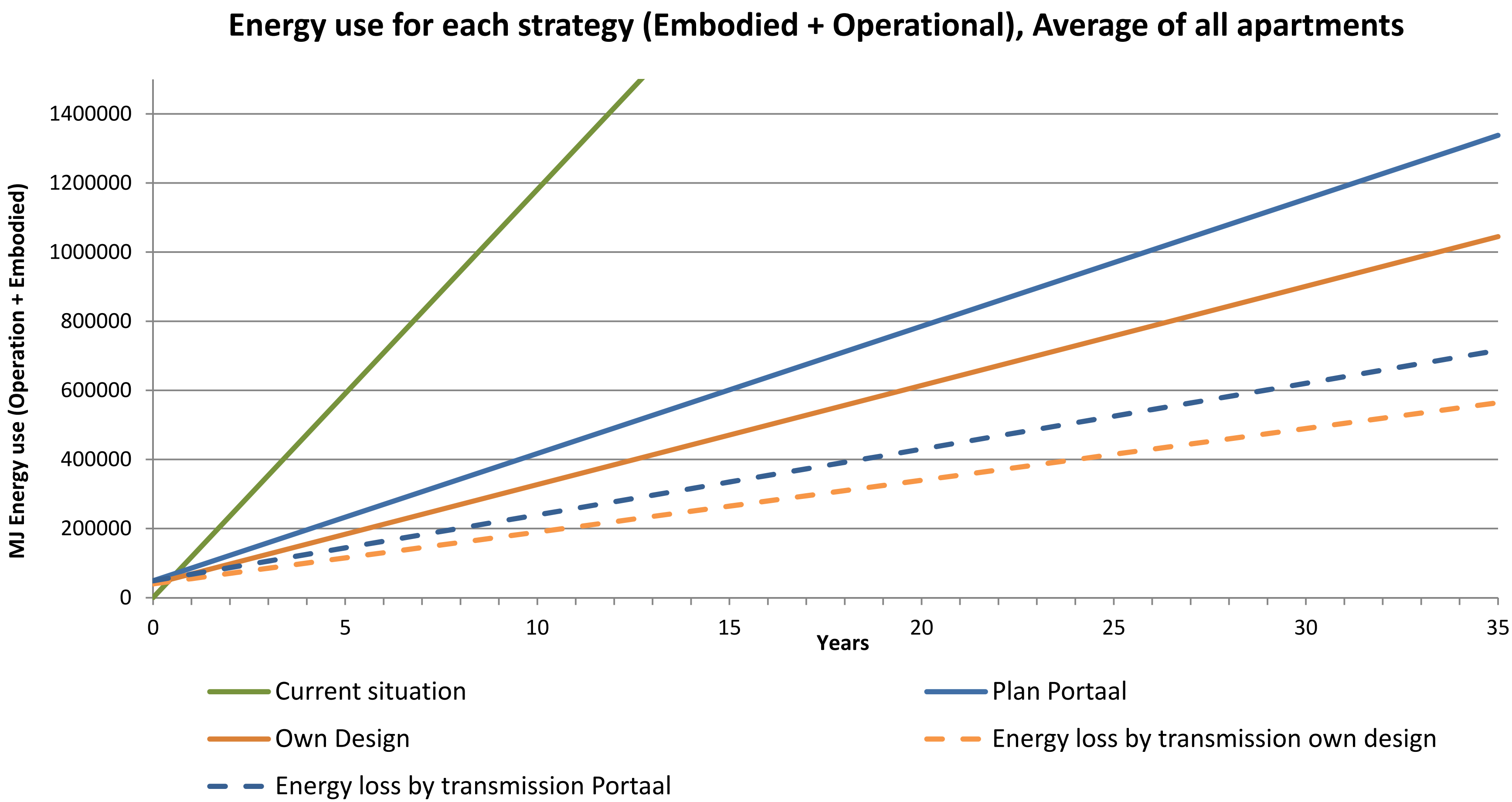
Weighted average of all apartment types



Design – Comparison

Energy use 35 years

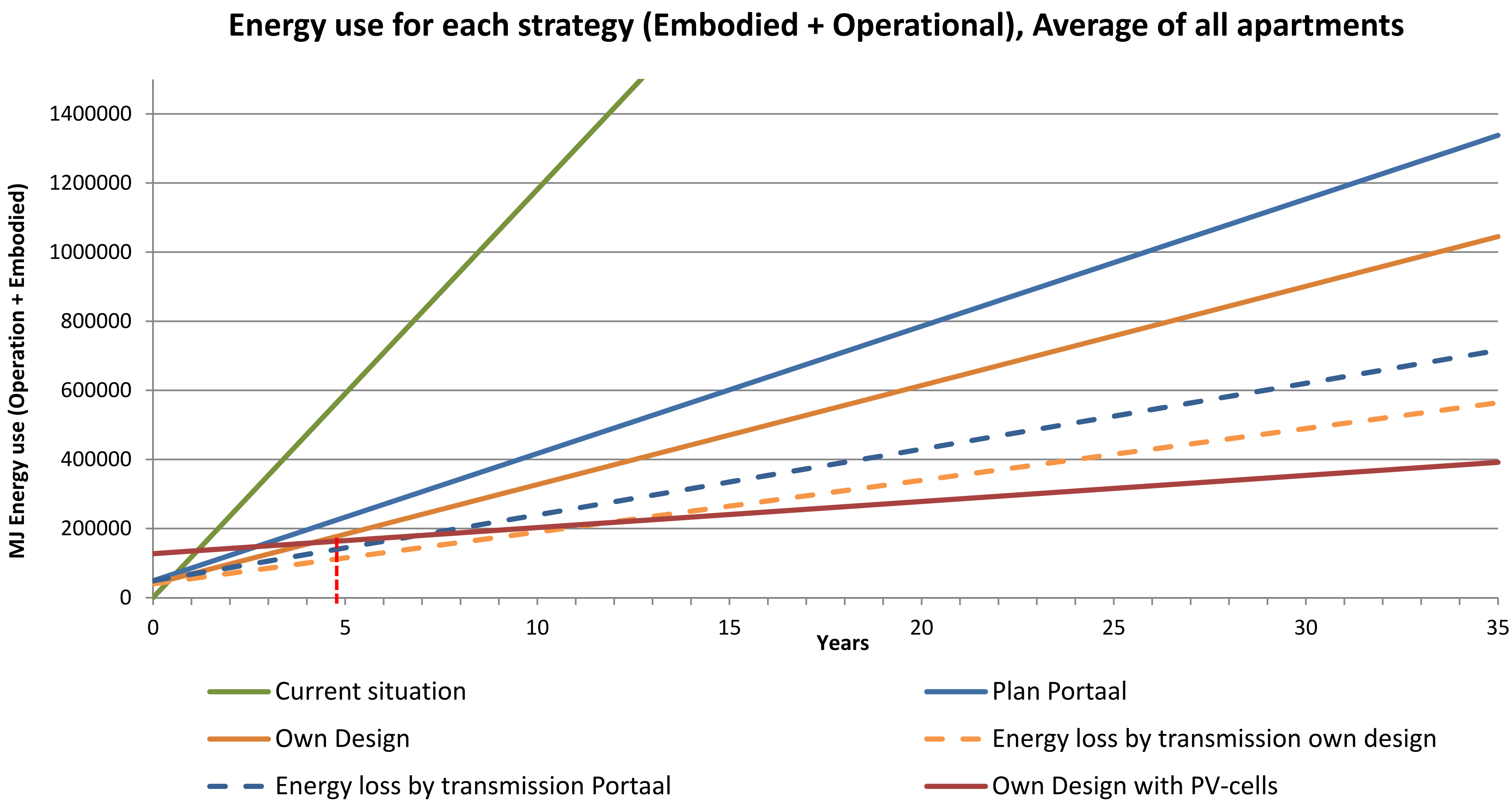
Weighted average of all apartment types



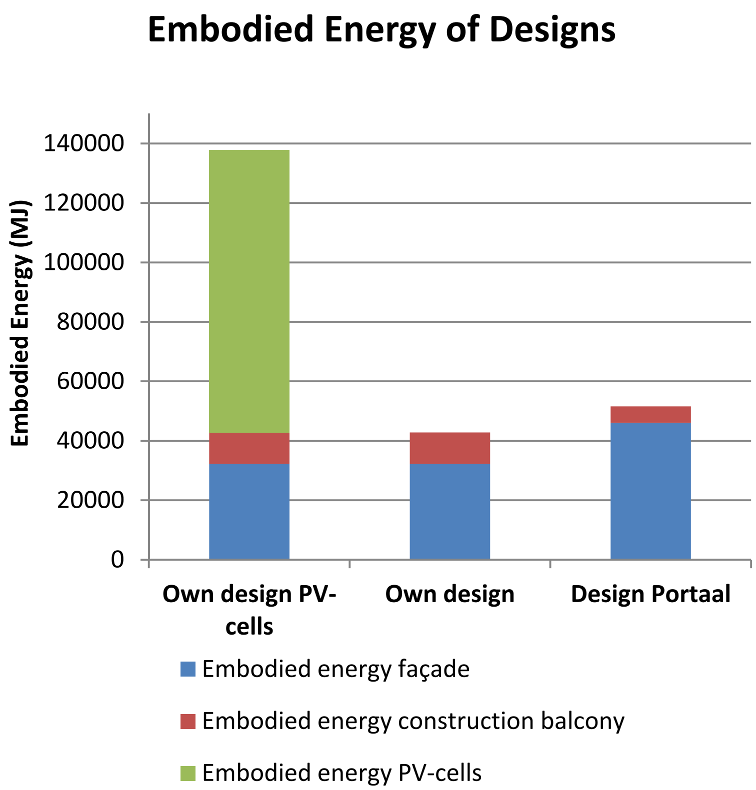
Design – Comparison

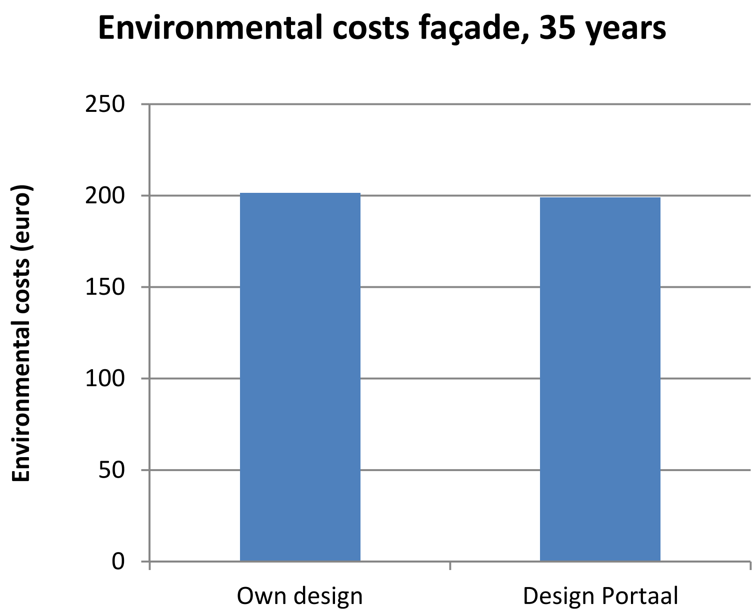
Energy use 35 years

Weighted average of all apartment types



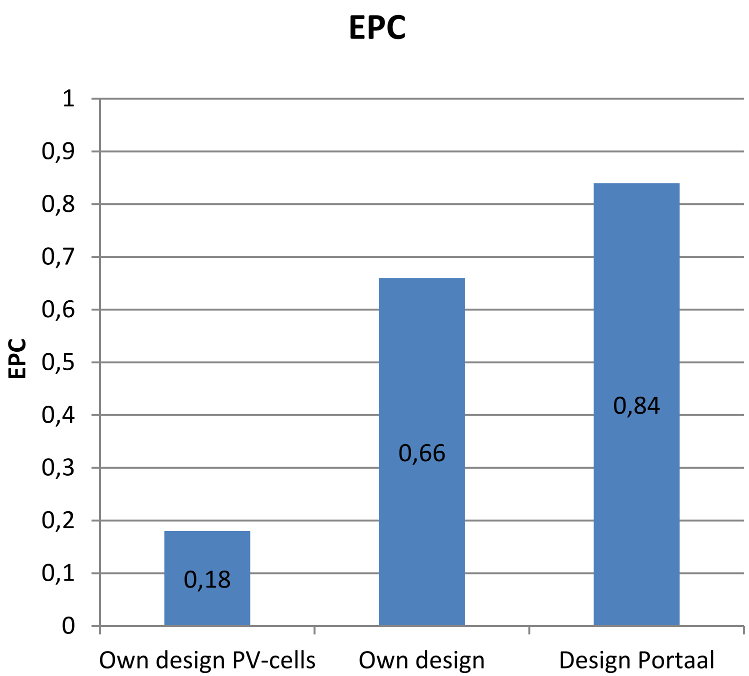
Weighted average all apartments

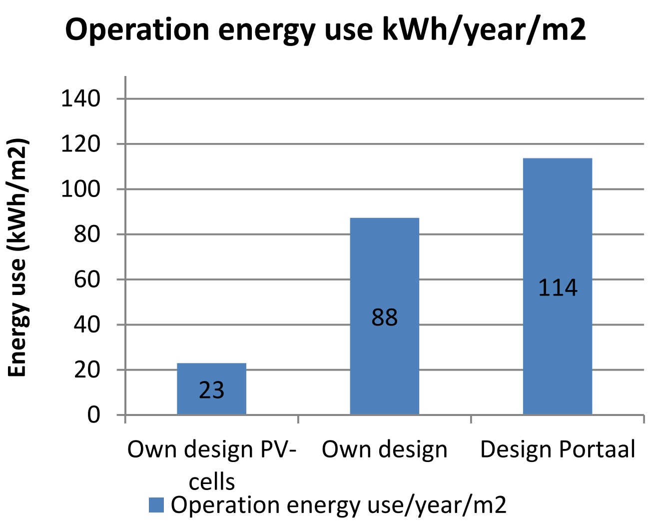


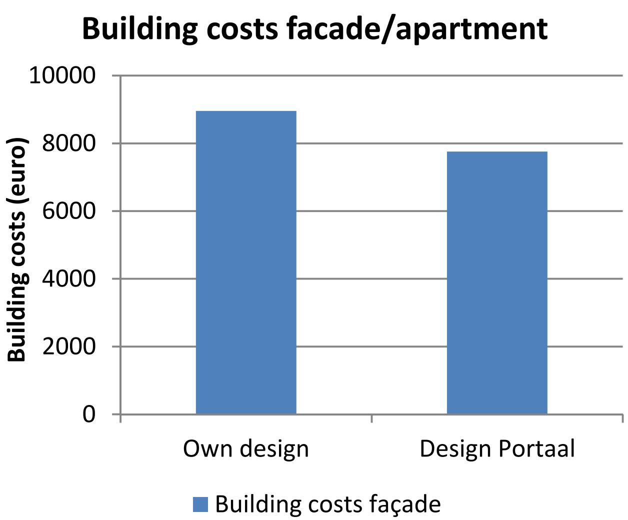


Design – Comparison

Weighted average all apartments







Main research question

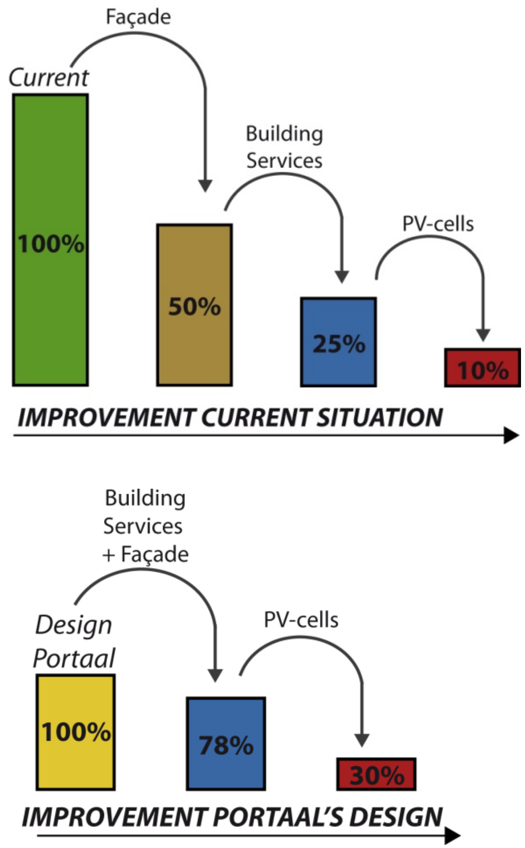
How can the façade of a post-war residential building be refurbished, to make the **operation energy and embodied energy (life cycle energy) as low as possible**, while also considering other factors that influence the environmental impact?

Conclusion: 3 Steps

-Building skin → Right balance for: insulation, glass percentage, reusing and keeping of old materials, infiltration, materialisation, closing off cold bridges .
50% energy reduction compared to current.

-Building services → Good balance between ventilation, heat output system and heat provision with a high efficiency. Domestic hot water, insulation of pipes, sunshading.
25% energy reduction compared to current.

-PV-cells/solar collectors → Limitation due to roof area.
15% energy reduction extra.



Design – Conclusions

Recommendations

General

-Follow the previous 3 Steps

Portaal

-Portaal uses good materials for the façade, but the insulation values should be higher and they should use PV of Solar cells to lower the energy use.

Research

-Other software than EPC to see exact (heating) energy use and indoor comfort

-More exact values for building costs

-Embodied energy of the building services

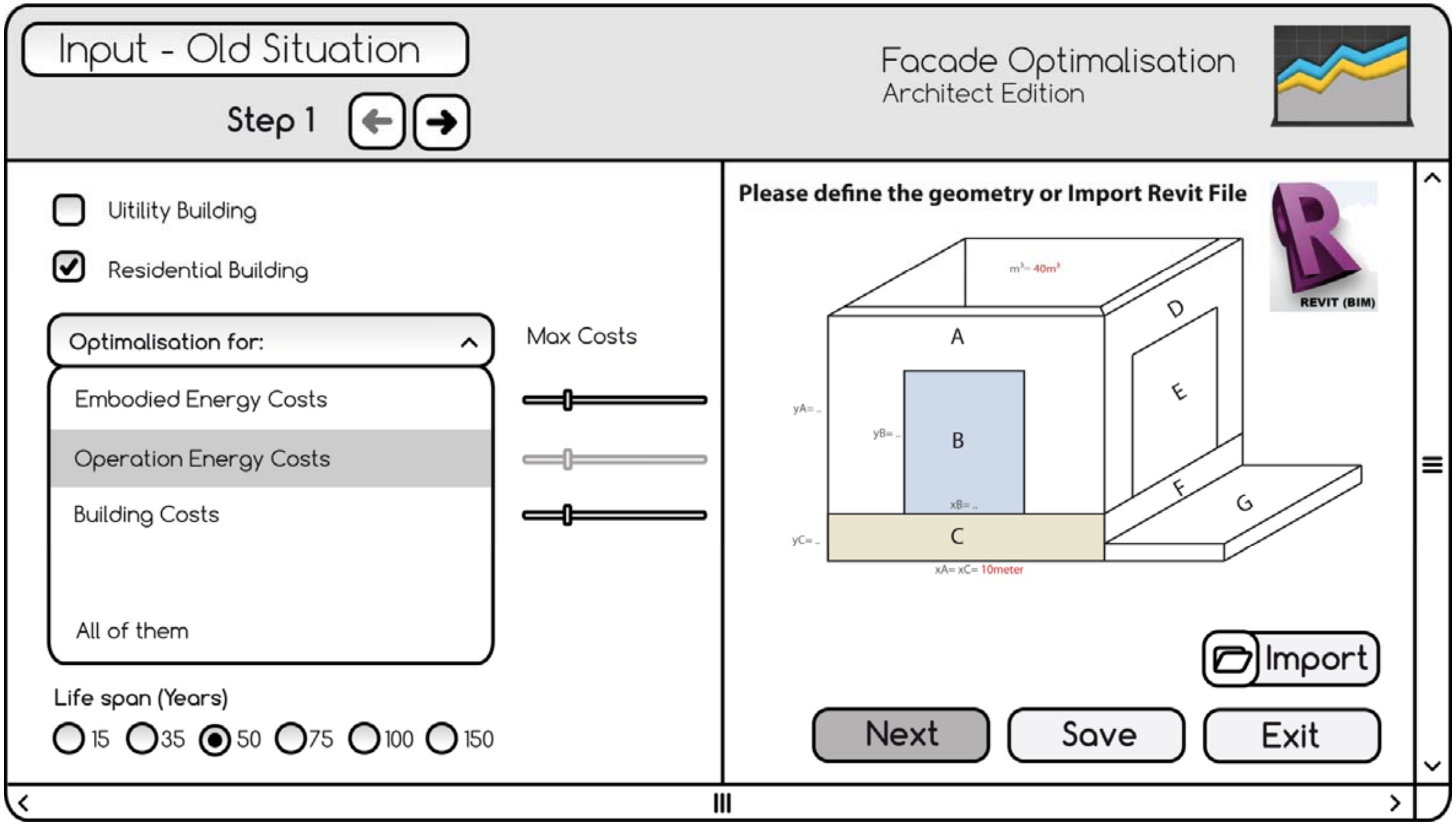
-Demolition energy

Design tool

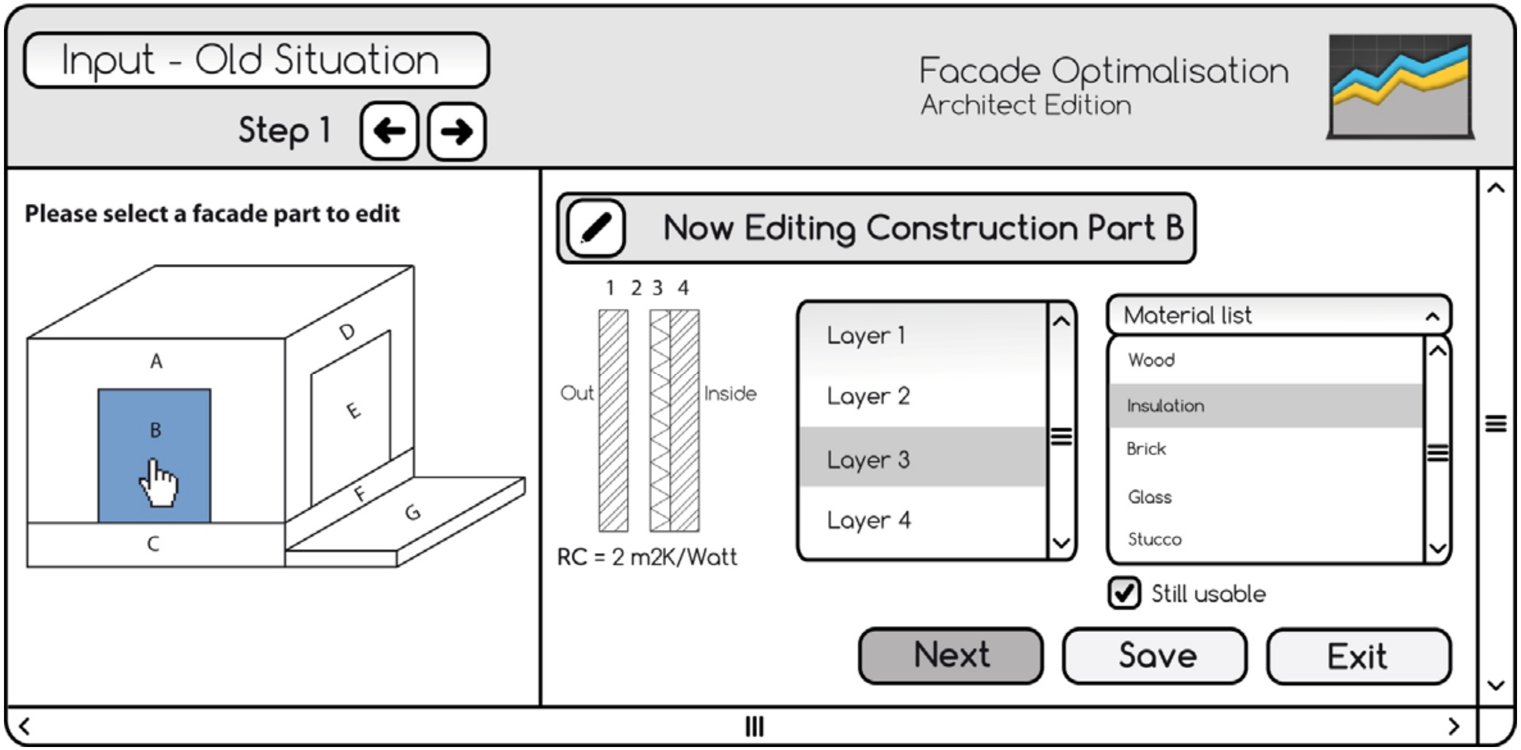
-Also more variations for architectural options in the design approach.

-All different aspects for design integrated into one 3D software tool.

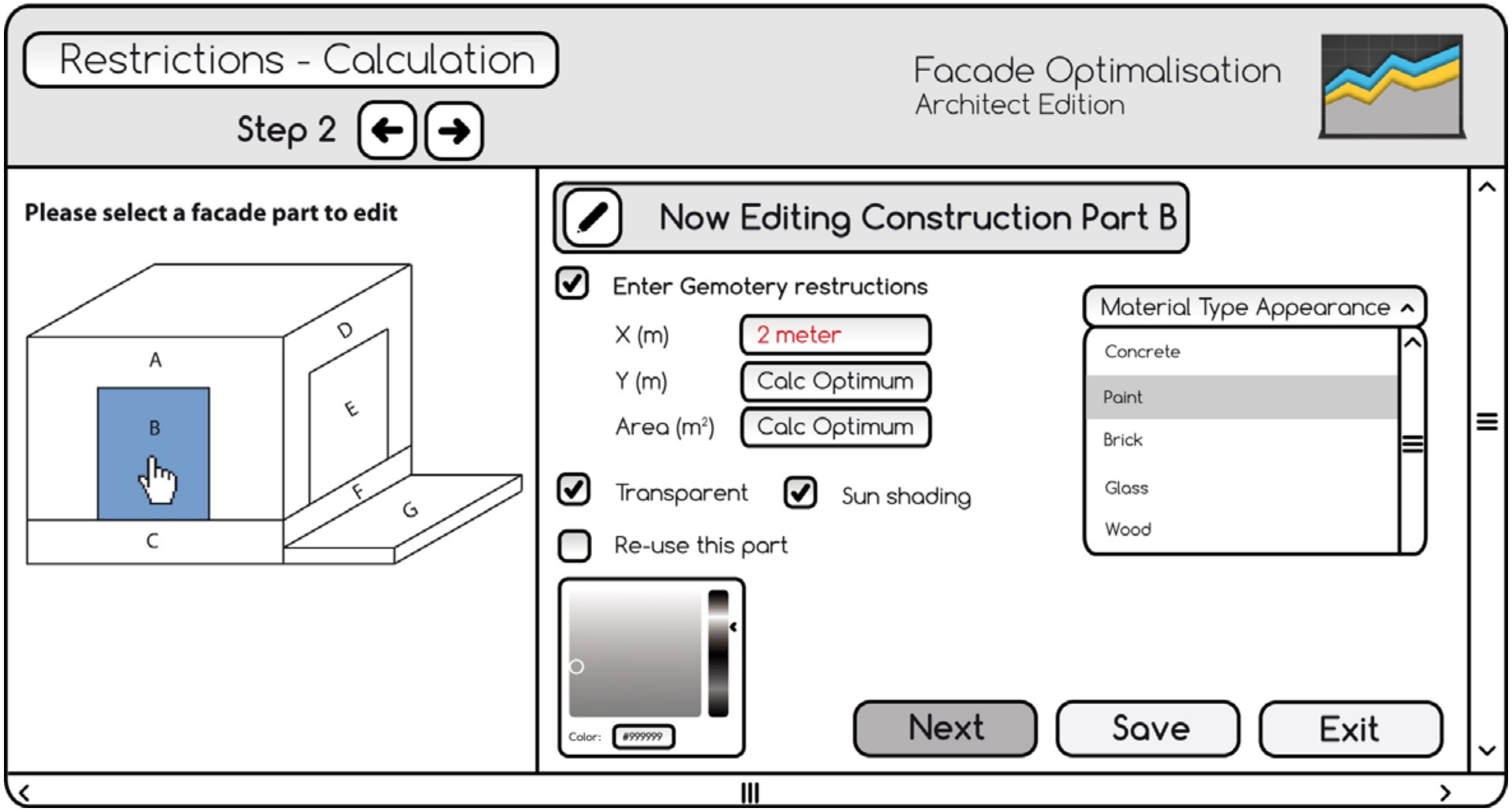
Future research – Integrated design tool



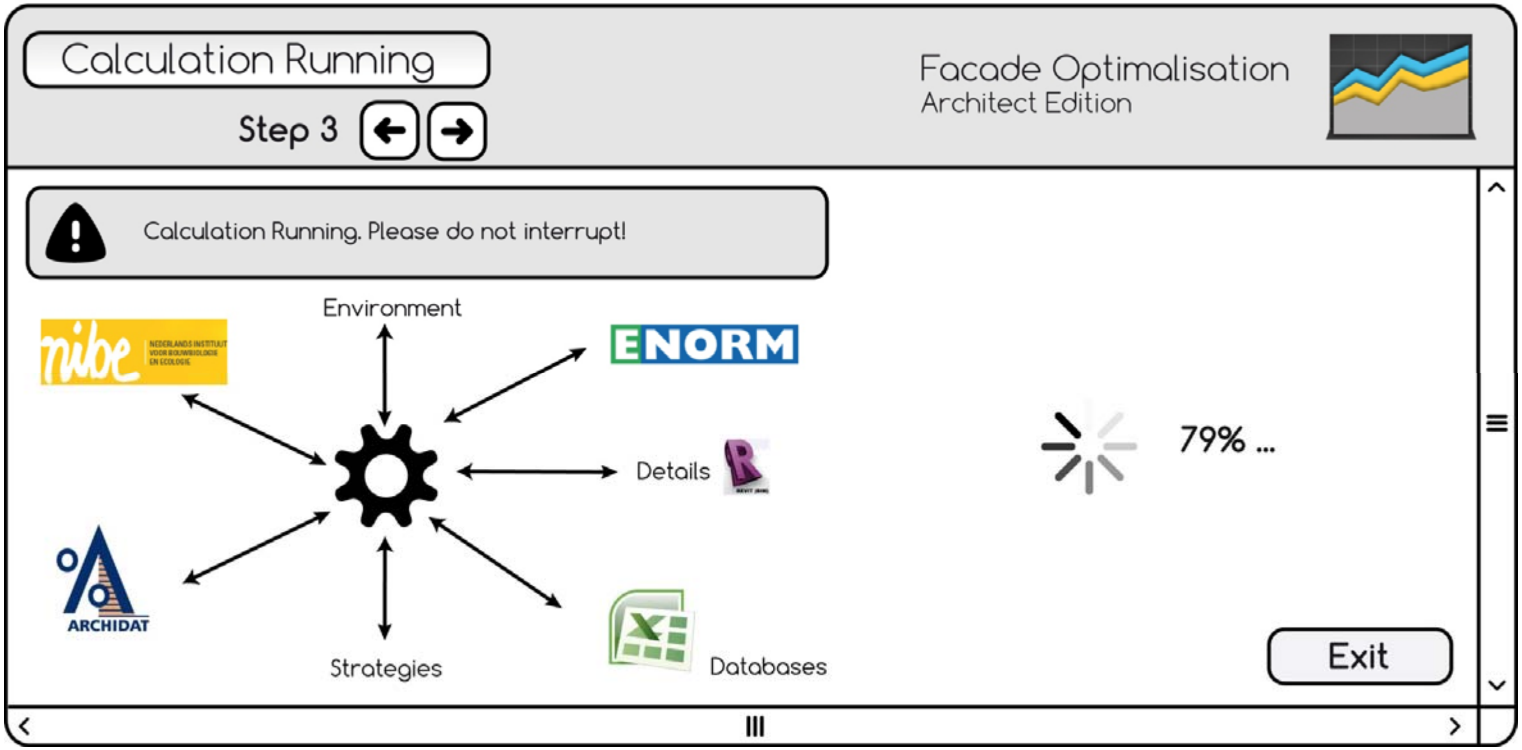
Future research – Integrated design tool



Future research – Integrated design tool



Future research – Integrated design tool

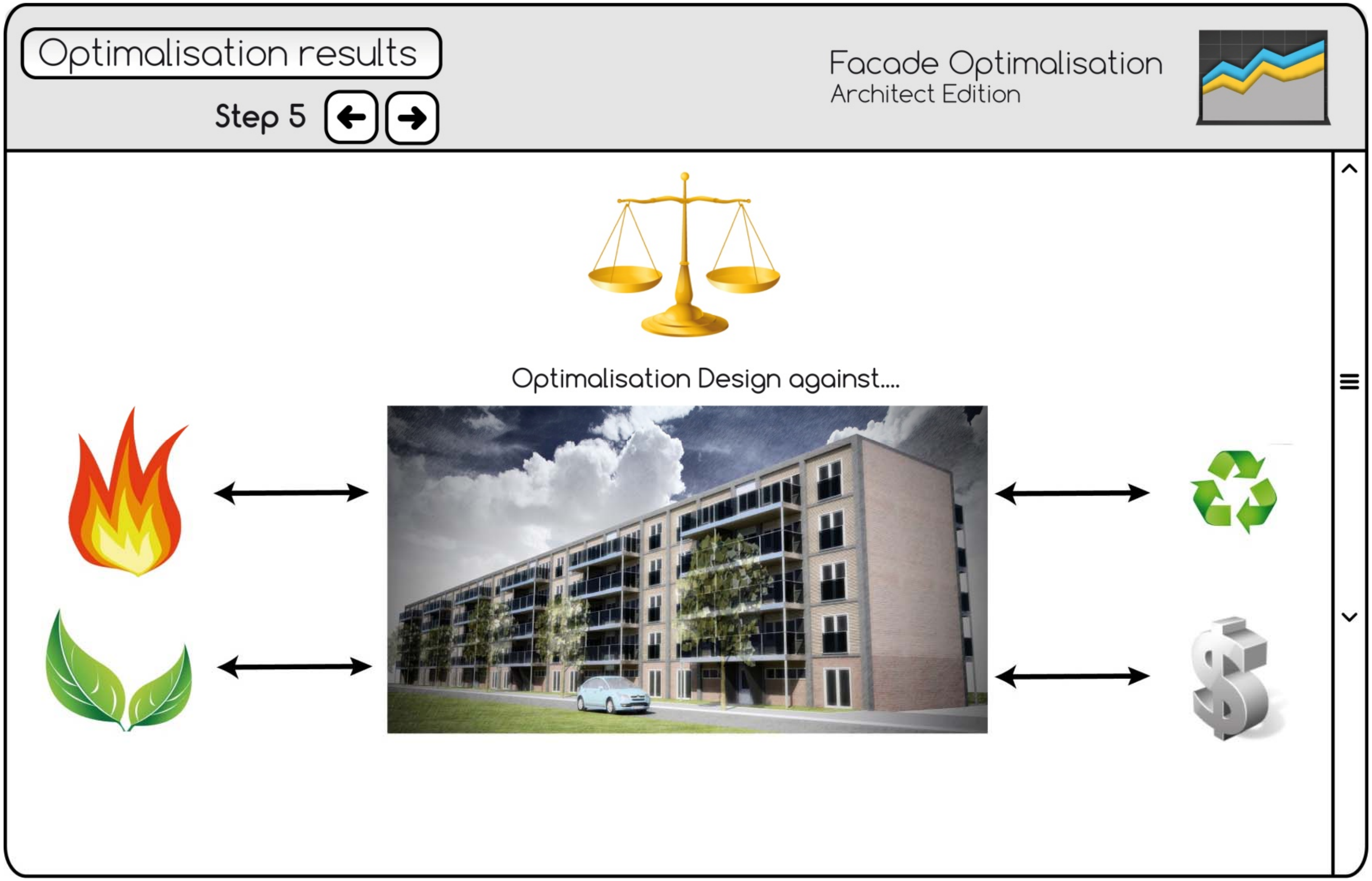


Design – Conclusions

Future research – Integrated design tool

Design – Conclusions

Future research – Integrated design tool



Thank you for your attention!