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the European Commission's in-house science service

Serving society
Stimulating innovation
Supporting legislation

Combining Safety, Energy Efficiency and Sustainability in Building Design

Paolo Negro
JRC.E.4 Safety and Security of Buildings

BIBM Congress 2017

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The *Joint Research Centre*

Is a *Directorate General* of the *European Commission*.

Is the European Commission's science and knowledge service which carries out research to provide independent scientific advice and support to *EU policy*.

The *Unit Safety and Security of Buildings*

Is located at Ispra, in Italy.

Operates the ***European Laboratory for Structural Assessment***, the largest European facility to simulate dynamic actions on structures.

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elsa

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E.4: European Laboratory for Structural Assessment

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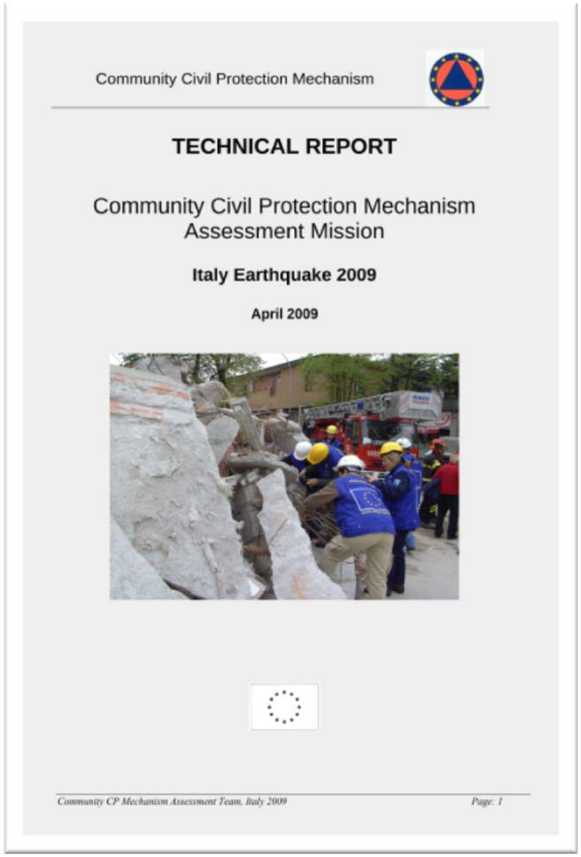
L'Aquila earthquake…

Coordination of a MIC mission to explore the possibilities for a collaboration among European Civil Protection agencies



Community Civil Protection Mechanism

TECHNICAL REPORT

Community Civil Protection Mechanism
Assessment Mission

Italy Earthquake 2009

April 2009

Community CP Mechanism Assessment Team, Italy 2009 *Page: 1*

http://ec.europa.eu/echo/files/civil_protection/italy_2009.htm

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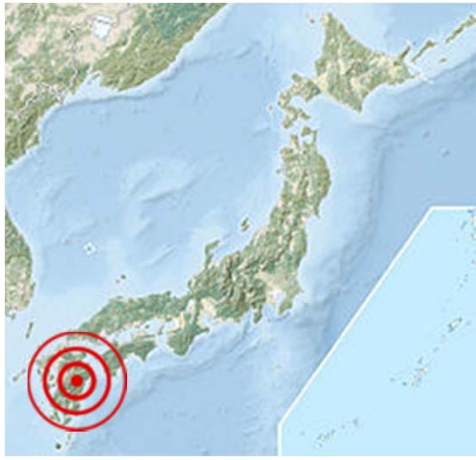
……2016 Kumamoto earthquake

Joint JRC/Japanese Building Research Institute reconnaissance



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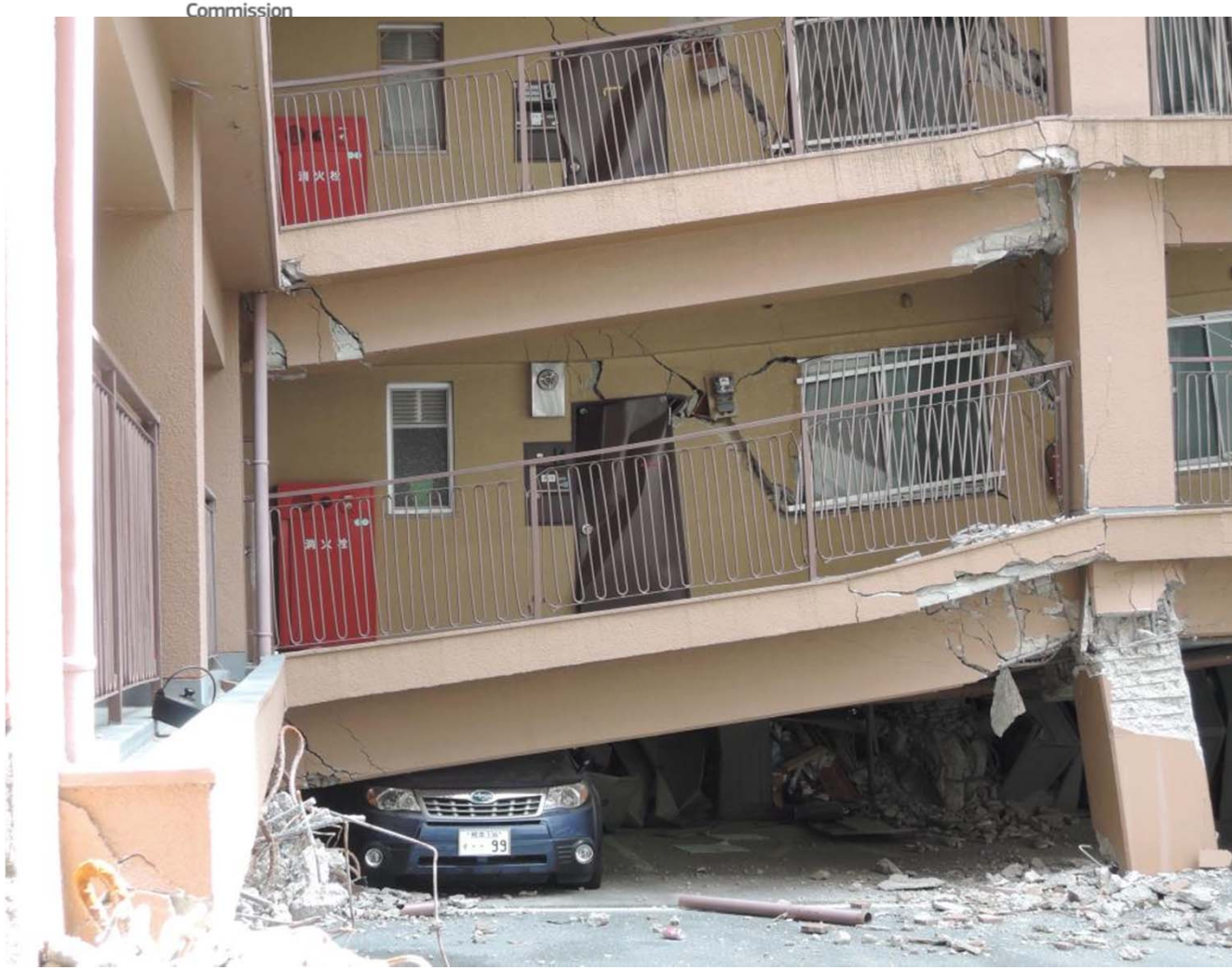

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Emilia earthquake, precast structures

SAFECLADDING project

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2011 Lorca (Spain) earthquake

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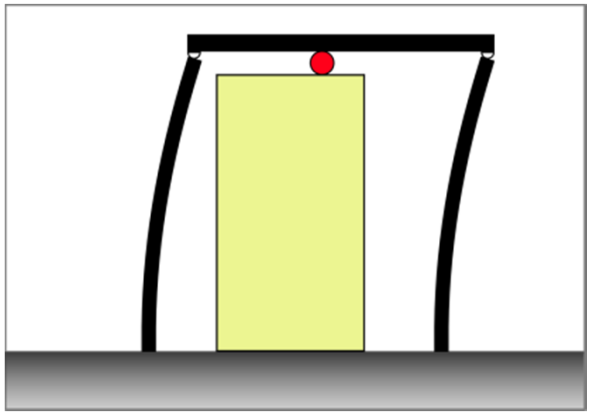
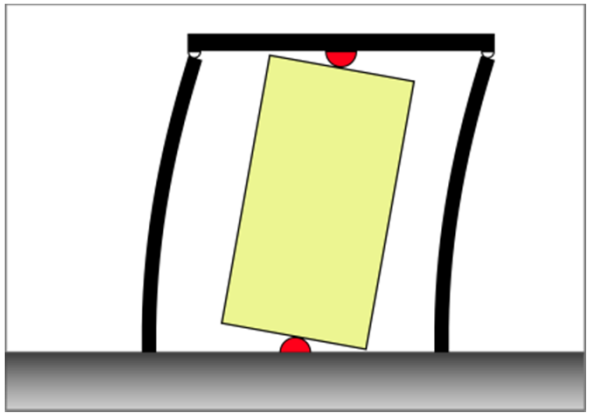
Current design practices



- The ***façade elements*** are:
  - simple masses,
  - without stiffness.

- The ***connections*** are:
  - conceived for self-weight only,
  - (and/or) out of plane loads;
  - designed for low displacement capacity.



- This does not hold true!
  And can lead to failure both panels and structure

Seismic behaviour of precast structures: A long story, many research partners

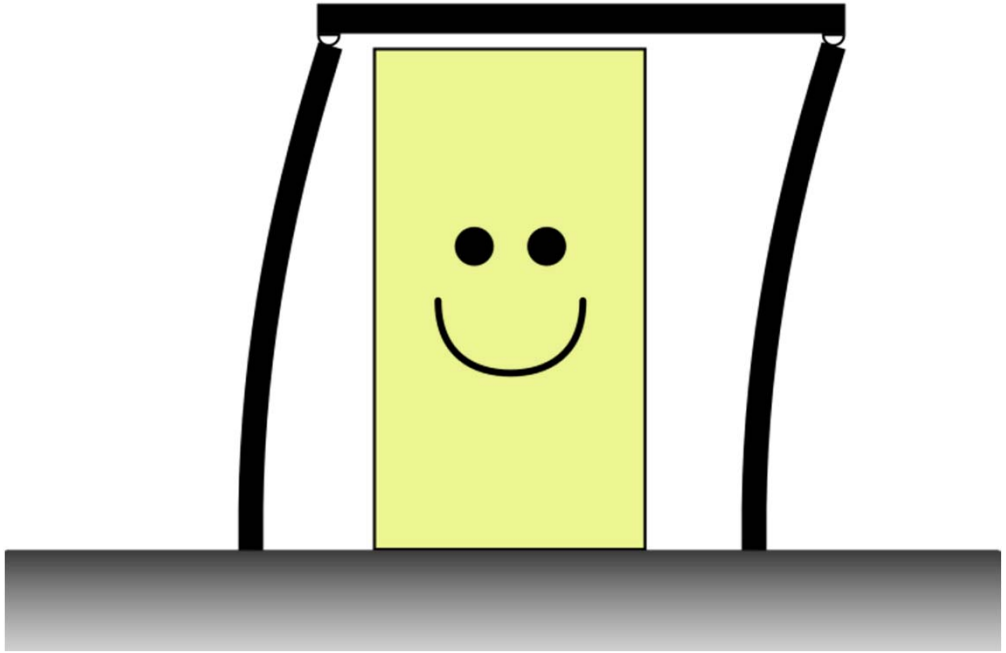
National Associations of Precast Producers:

- BIBM (EU)
- VBBF/ECS (DE/EU)
- Assobeton (IT)
- ANDECE (ES)
- ANPC (PT)
- SEVIPS (GR)
- TPCA (TR)

RTD Providers:

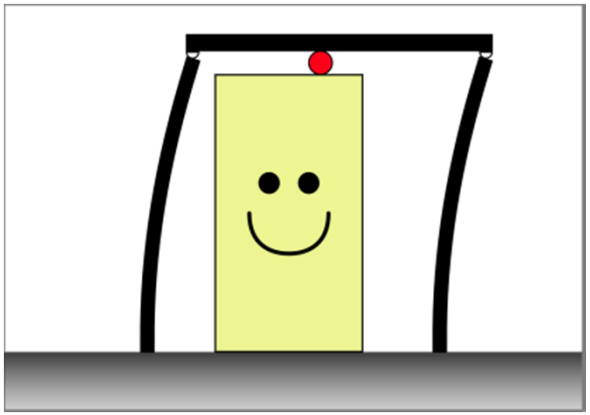
- ELSA (EU)
- Politecnico di Milano (IT)
- LNEC (PT)
- NTUA (GR)
- University of Ljubljana (SI)
- Technical University Istanbul (TR)
- Tongji University (CN)

Isostatic restraint configuration

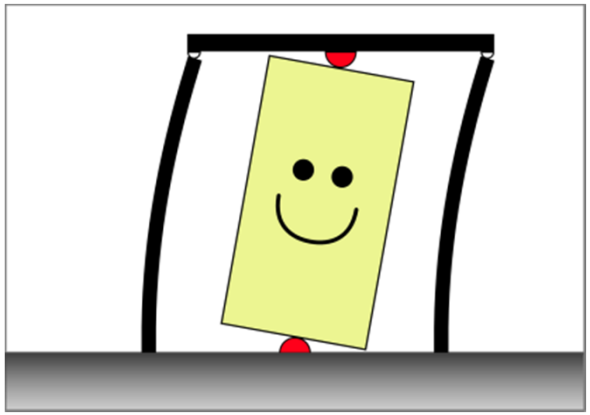


The connections between frame structure and panels allow mutual displacements that satisfy the deformation demands of the frame, uncoupling it from the kinematic behaviour of the panels. (**WP2**)

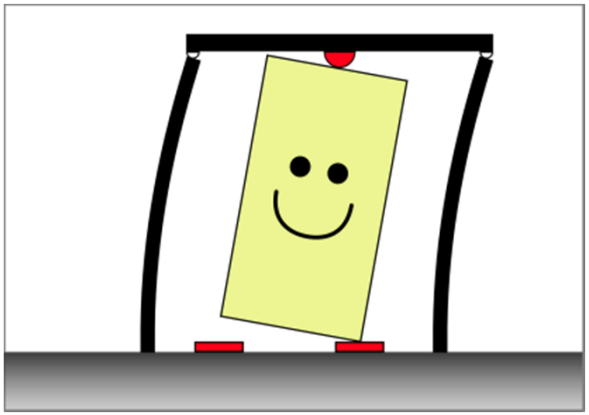
Isostatic configuration: ***design strategies***



Isostatic Sliding Frame



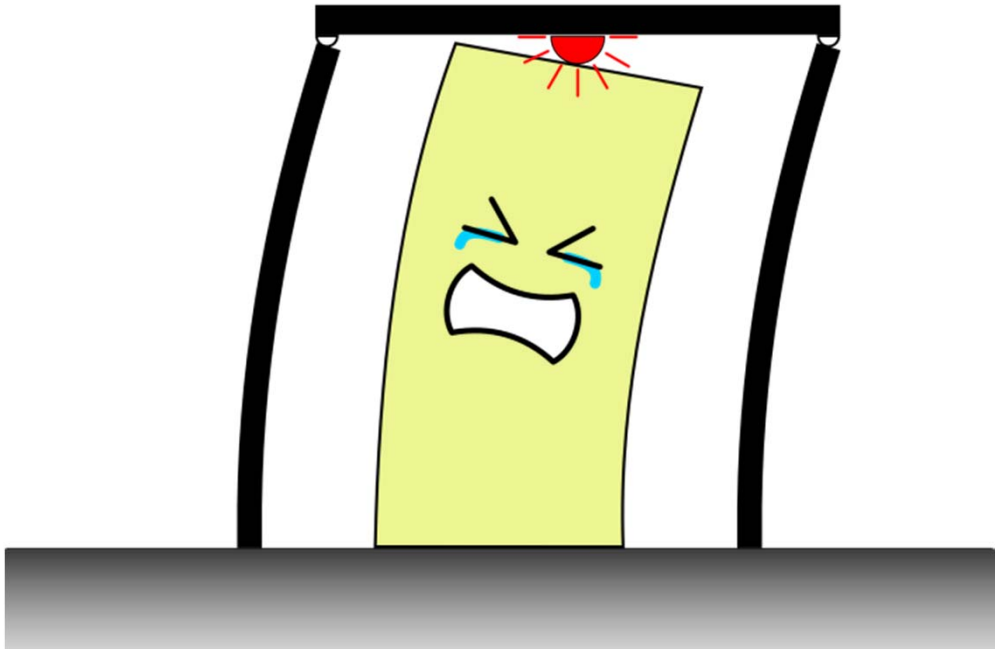
Double Hinged Panel



Rocking Panel

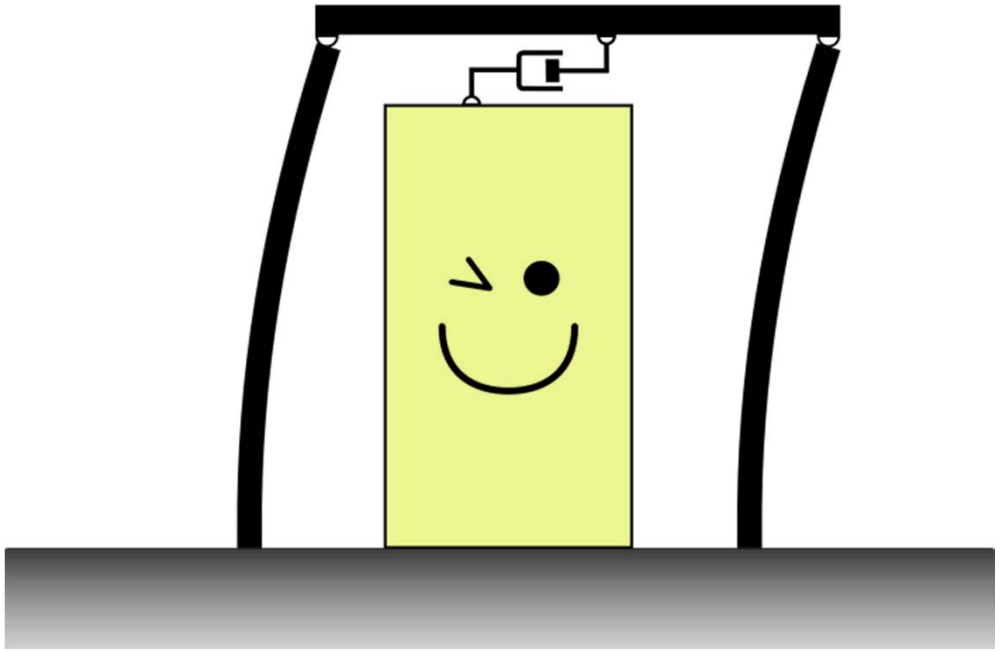
Different strategies for the *Isostatic Restraint Configuration* have been tested, both for *vertical* and *horizontal panels*. Similar configurations also tested for the *Dissipative Restraint Configuration*.

Integrated restraint configuration



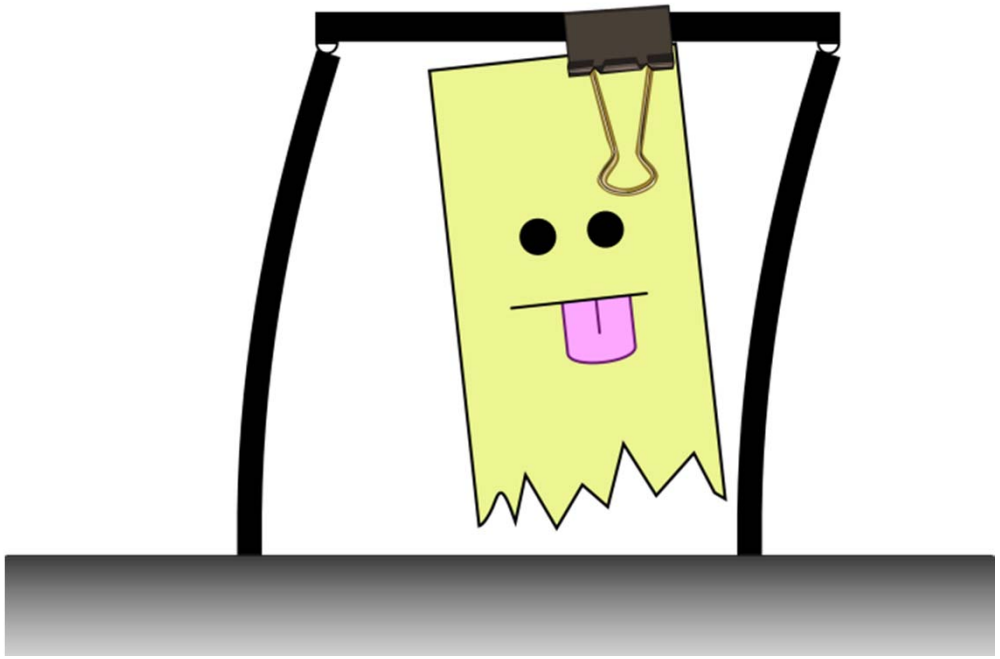
The frame and panels are restrained, the displacement is coupled between the parts. The connections must be over-proportioned to bear the higher stress level requested. (**WP3**)

Dissipative restraint configuration



The joints between structure and panels (or among the panels) can dissipate energy. The overall building response can be balanced to *reduce* displacements keeping *low loads* in the connections. (**WP4**)

Backup Connections



The Backup Connections have to ensure the security against panels falling and overturning, once the main connections are jeopardized. These are suitable for the retrofitting of existing buildings. (**WP1**)

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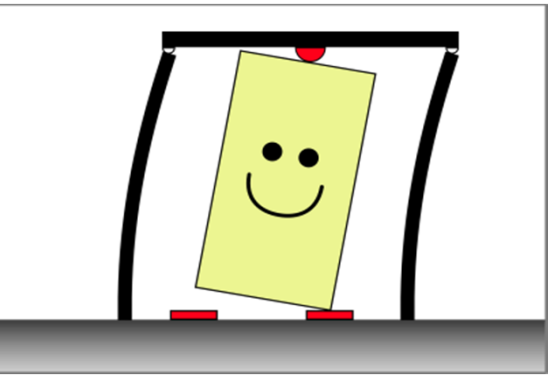

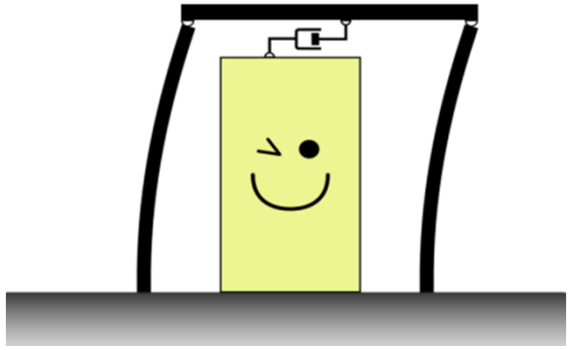

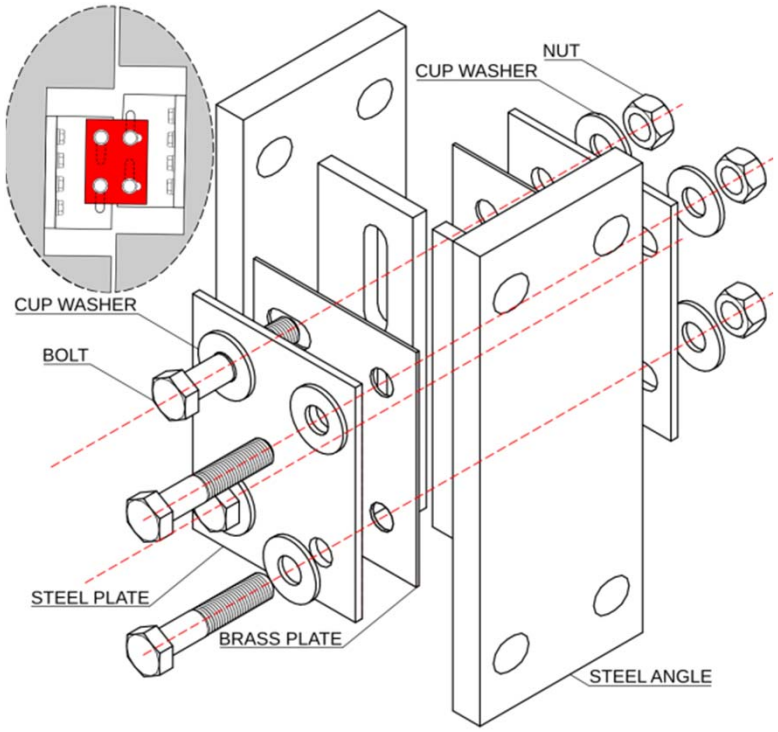

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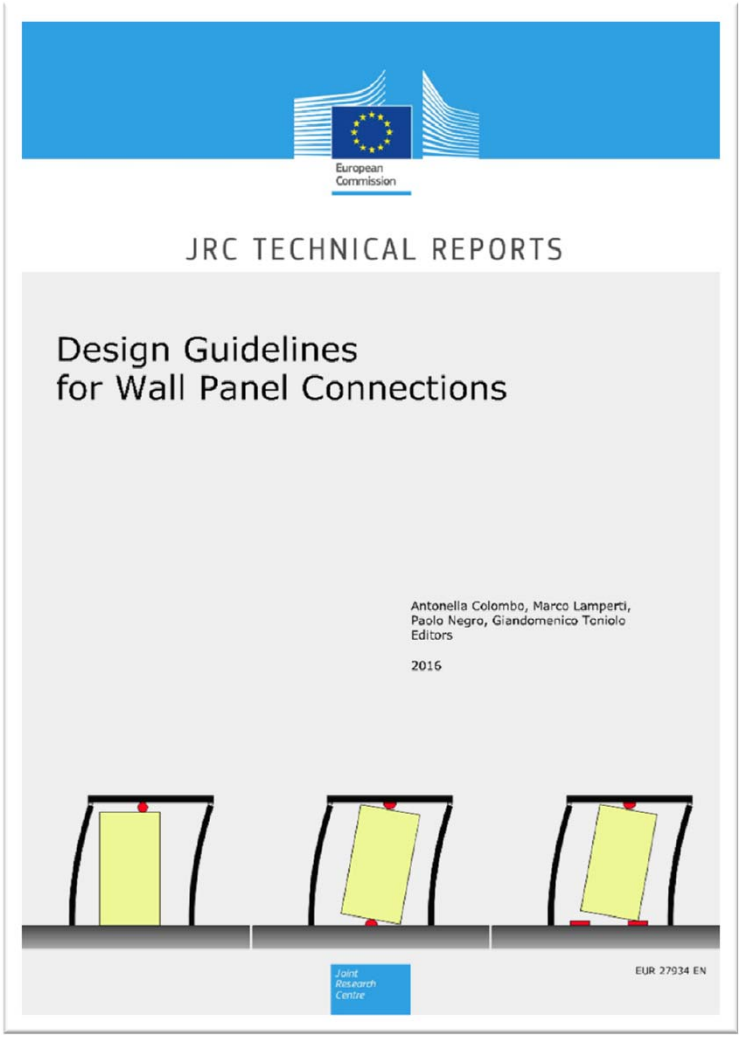
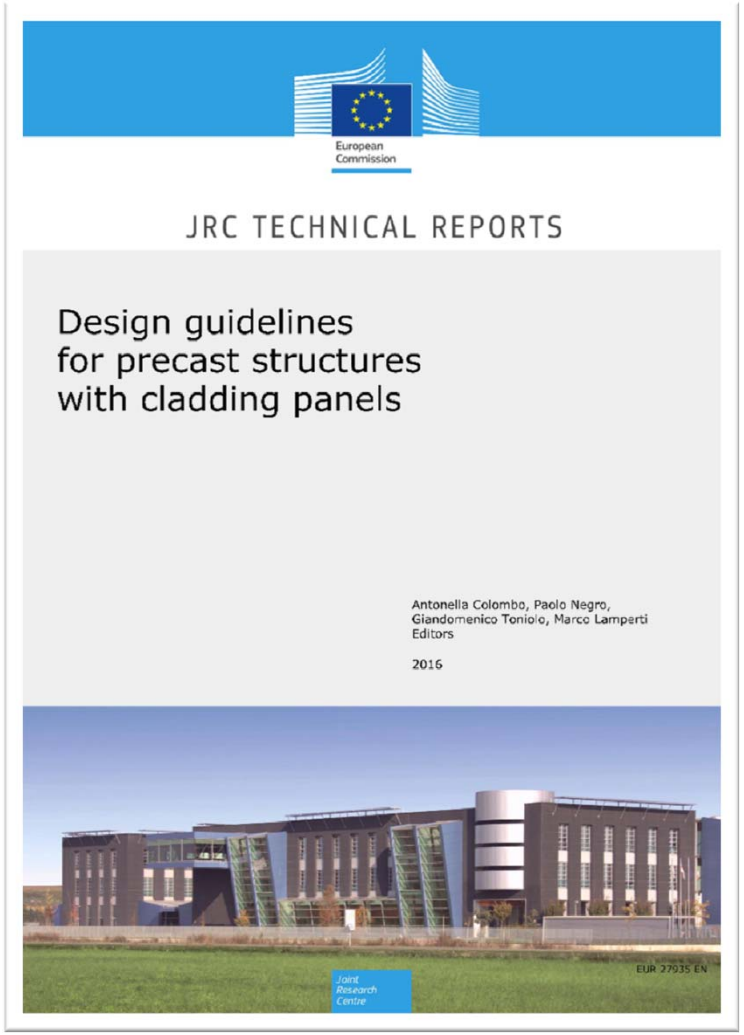
SAFECLADDING: Design Guidelines

http://doi.org/10.2788/546845





http://doi.org/10.2788/956612

- Available in **EU BOOKSHOP**

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bound to adoption by ISO TC71

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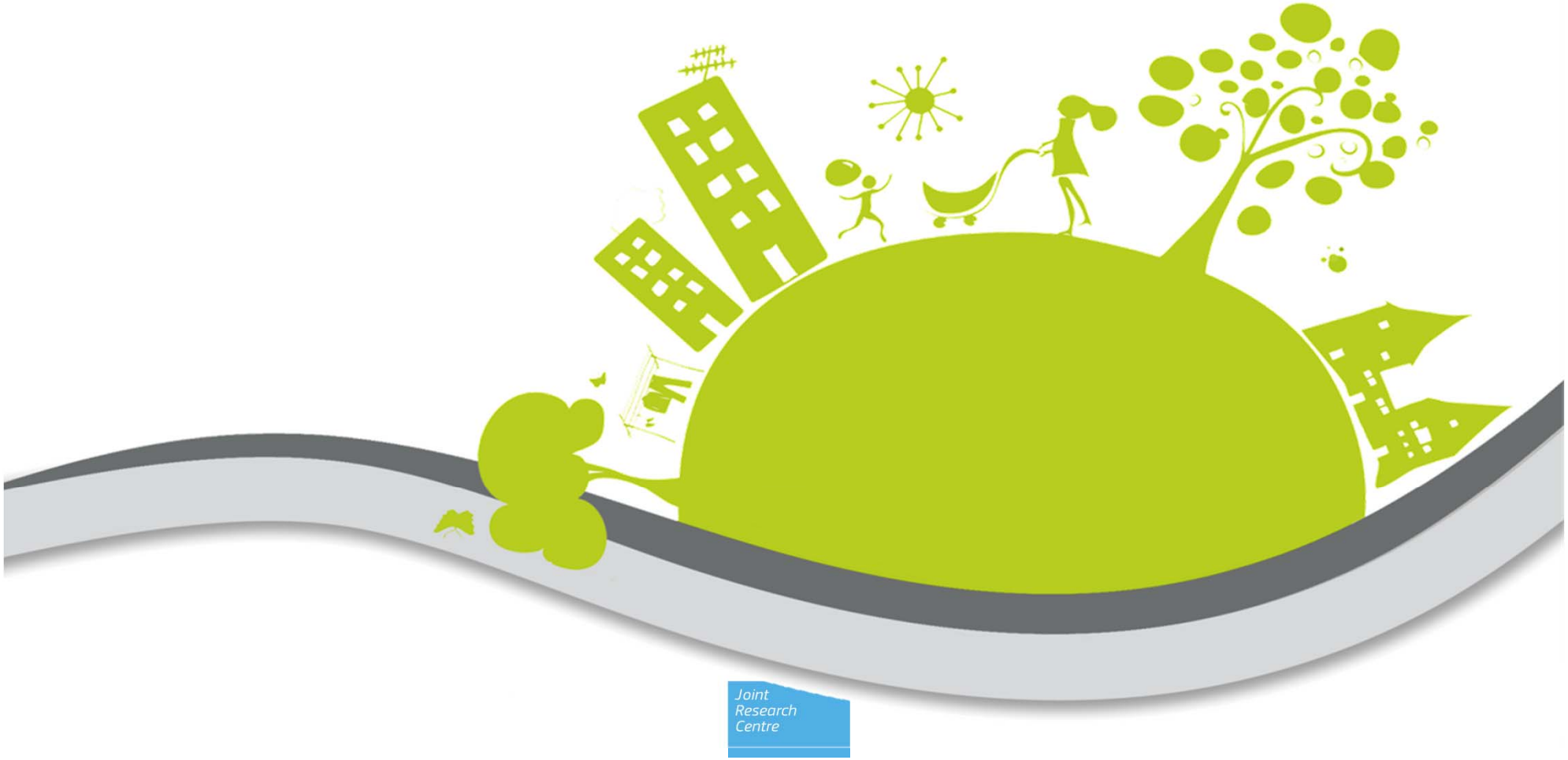
Life-Cycle Analysis (LCA, from cradle to grave…)



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Life-Cycle Analysis (LCA, from cradle to grave…)

Many LCA assessment procedures….

- **Different criteria**
- **Lack interoperability**
- **Long and difficult**

- **Only a posteriori….**

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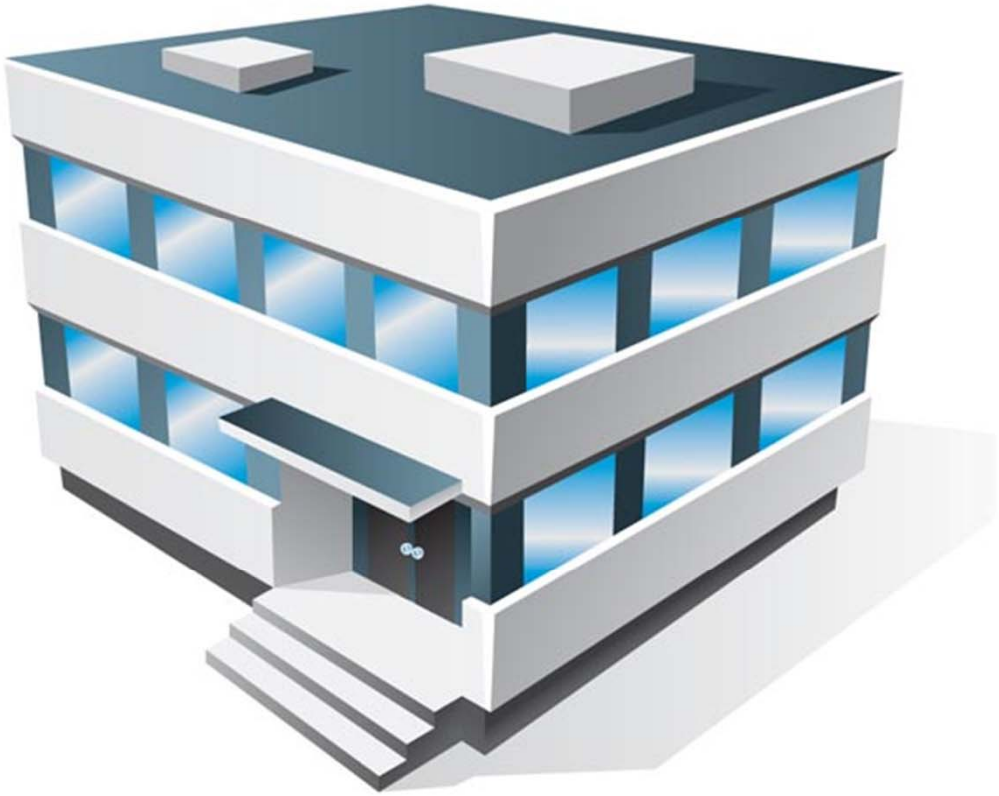

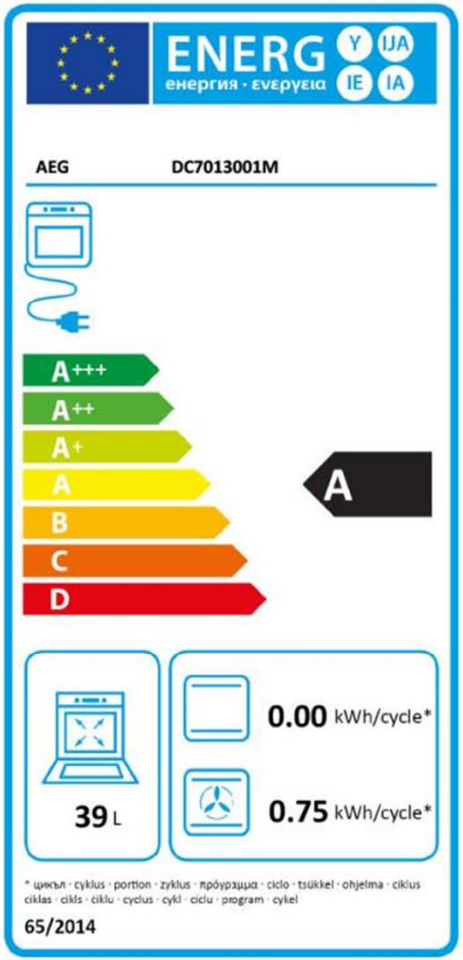

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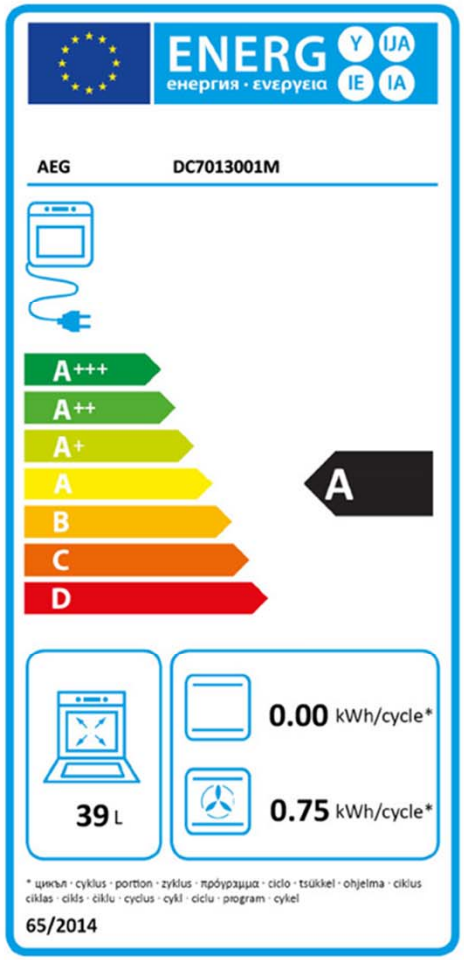

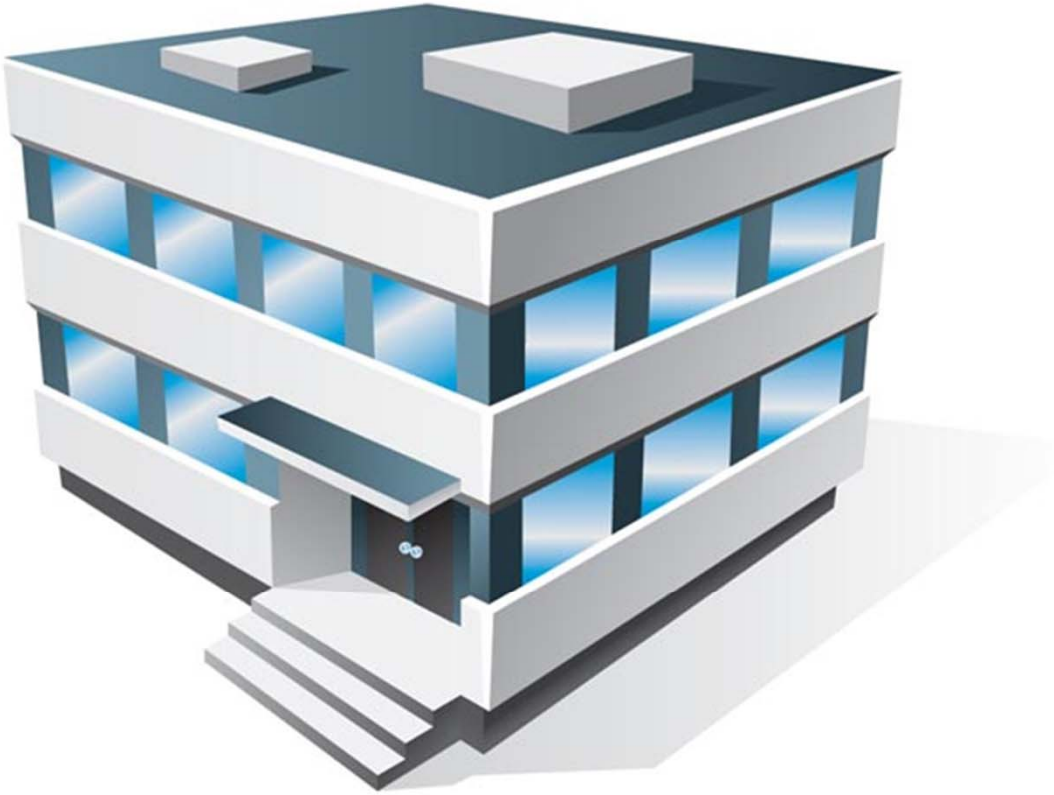

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Look at the whole process

SSD Methodology

Sustainable Structural Design (SSD) is a methodology aiming at supporting the general design process of buildings.

The methodology combines the structural and the environmental aspects of the buildings and summarises them in a single final parameter, provided in economic terms.

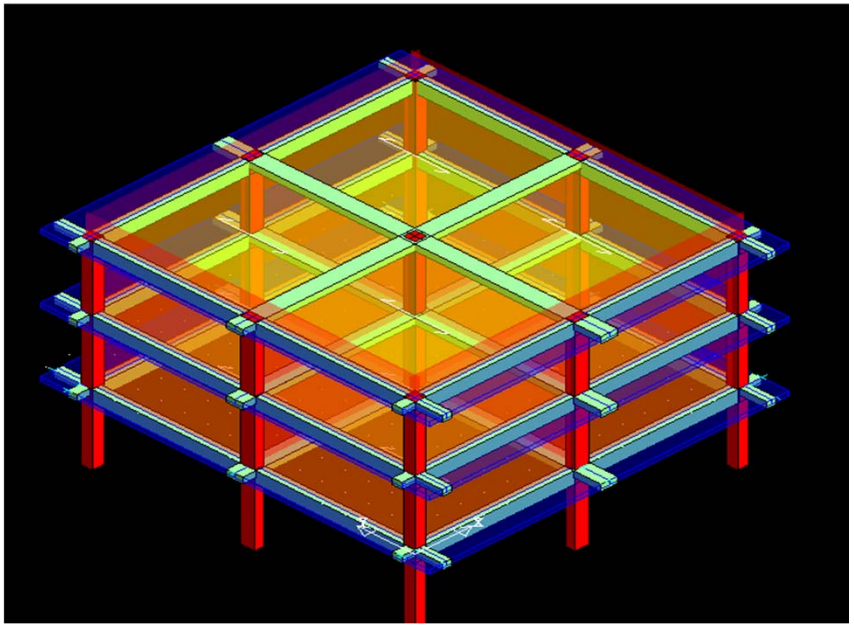
Application to a building

1) Precast Structure

- Real scale building
- Built and tested at ELSA (SAFECAST and SAFECLADDING)
- No walls, hinged connections

2) Cast-in-situ Structure

- Designed according to EC8
- Reinforced concrete structure
- Same architectural layout



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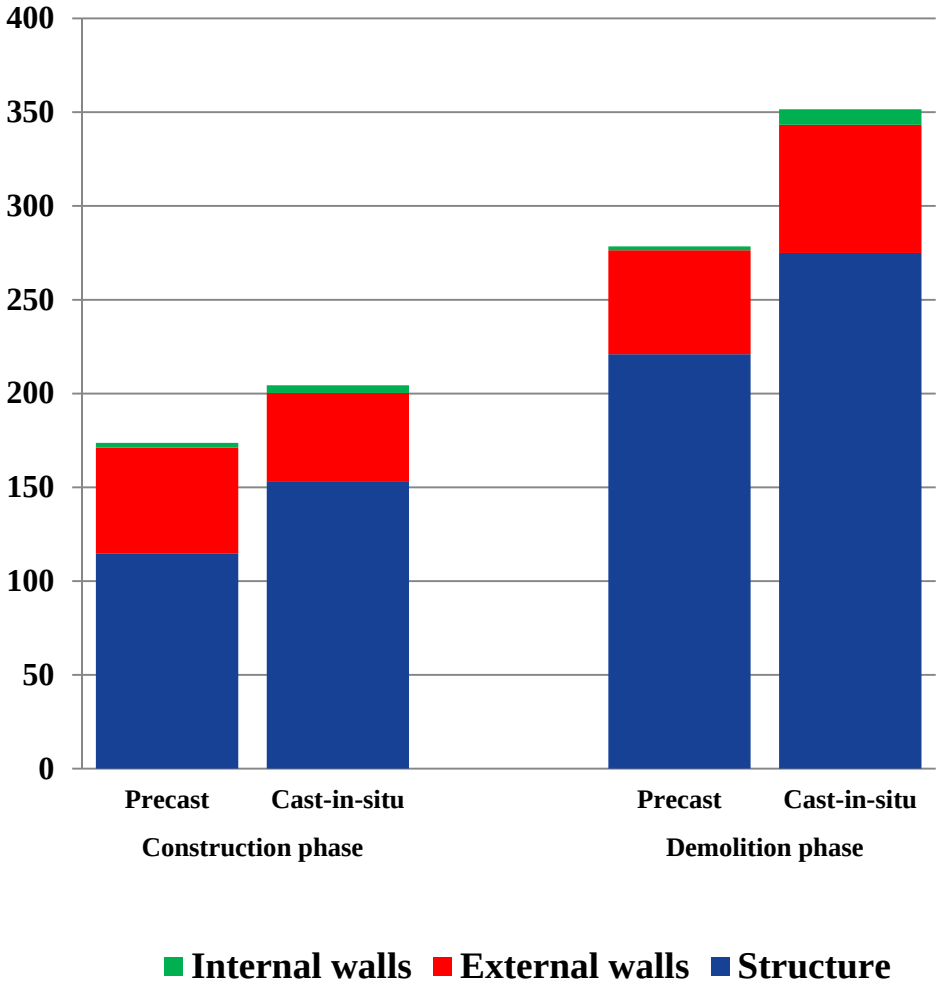
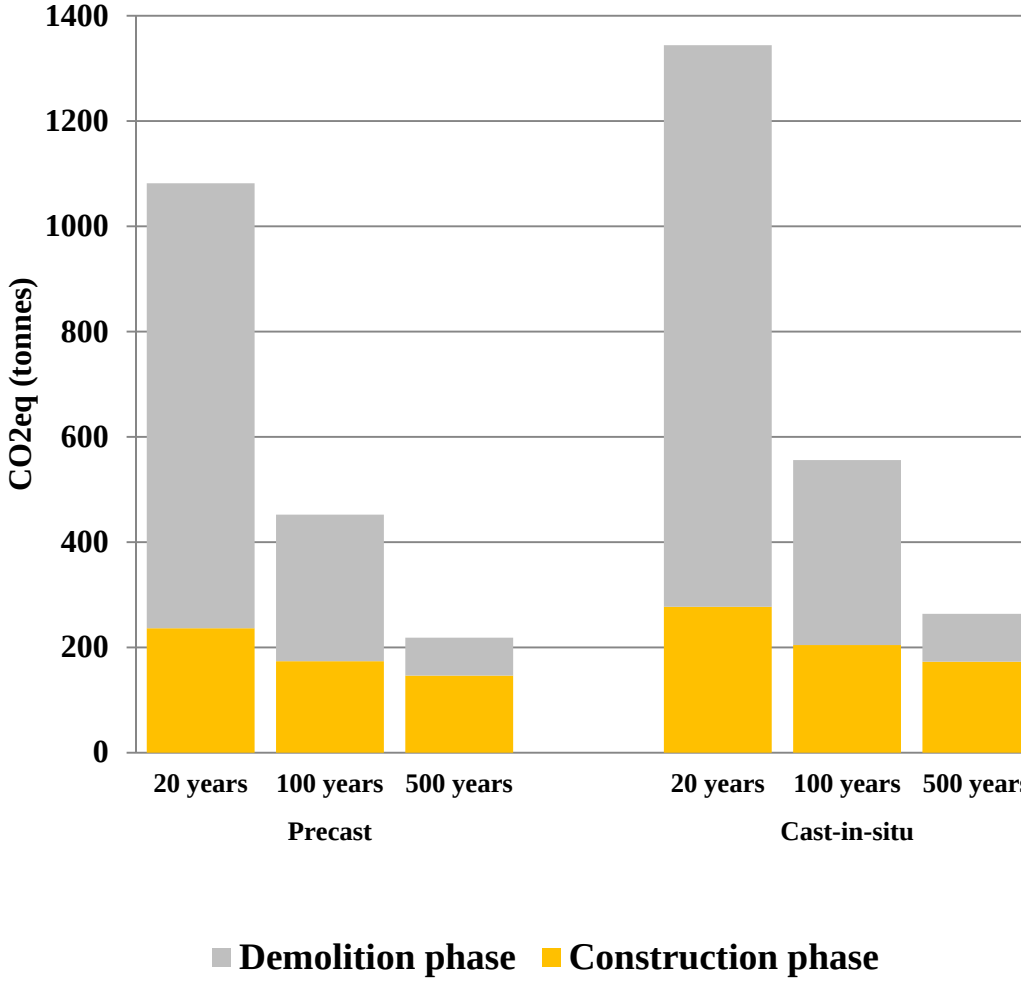
Life-Cycle Assessment





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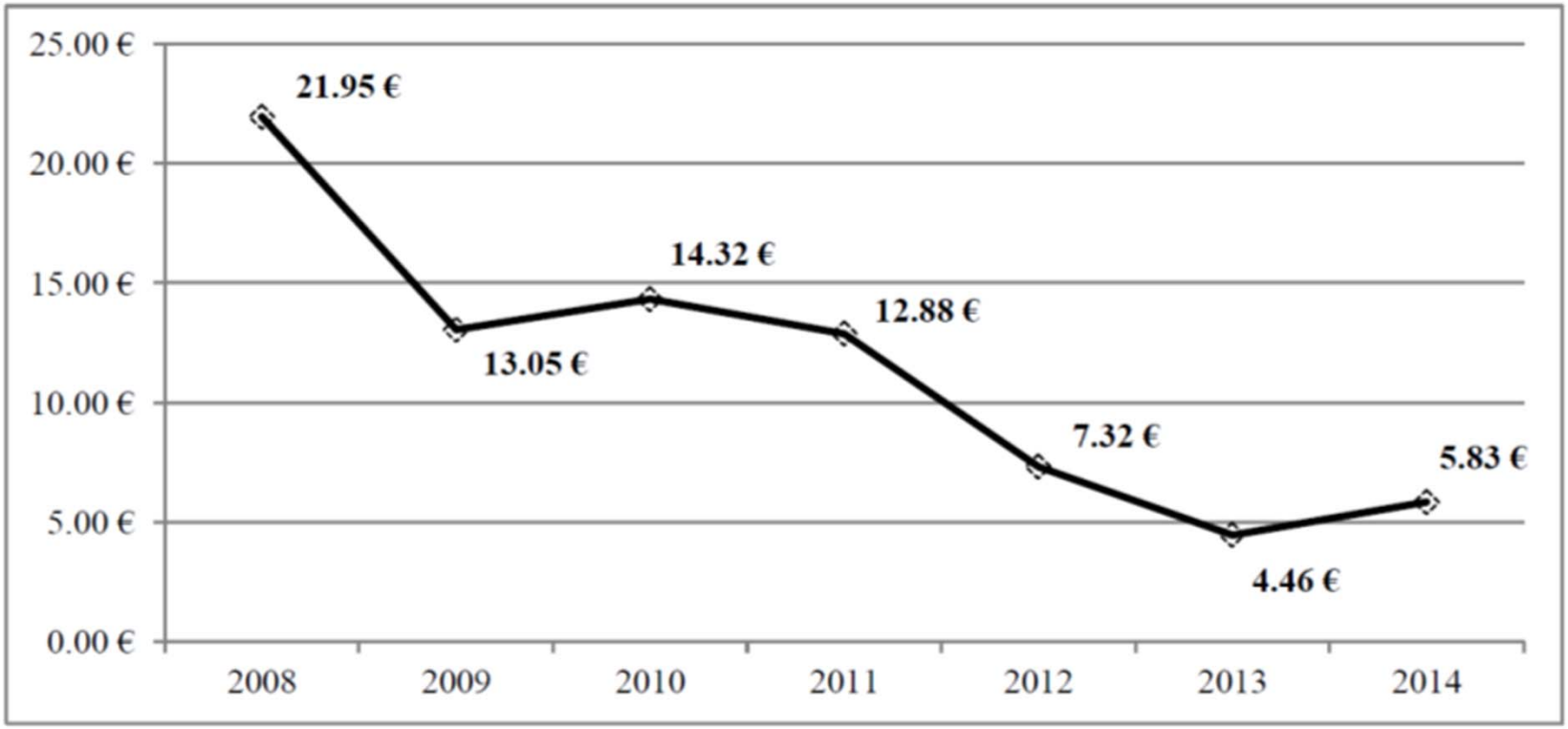
Cost of equivalent CO_2 emissions:
European Union Emission Trading System



Energy Assessment

➢ ***For operation phase***

Climatic zone F → ENEA → Italian national data for office occupancy

Electric consumption

ZONA CLIMATICA	INDICATORE [kWh/m² anno]
A	155
B	156
C	139
D	125
E	90
F	52

Heating consumption

ZONA CLIMATICA	INDICATORE [m³/m² anno]	INDICATORE [kWh/m² anno]
A	0,3	2,9
B	3,0	28,8
C	6,0	57,6
D	9,0	86,4
E	10,9	104,6
F	23,1	221,8

According Buildings Performance Institute Europe (BPIE) data: The annual average energy consumption in the non-residential sector is **280 kWh/m².**

Electricity: 52 kWh/m² year × (263,5 m² × 3)× 50 years = **2.055.300 kWh**

Gas: 23,1 m³/m² year × (263,5 m² × 3) × 50 years = **913.027 m³ gas**

(Simplified) Structural Performance Assessment

- **Definition of Damage Levels (Limit States):**

Low damage: *start of the damage for non-structural elements*
Heavy damage: *damage of all non-structural elements*
Severe damage: *no-collapse requirement*
Near Collapse Limit State: *prevention of global collapse under a very rare event*

- **Cost Analysis:**

Initial **construction cost**,
Expected **repair / reconstruction costs** (including **downtime**)

- **Probability of exceedance** (from seismic map)

Structural Performance Assessment

Loss Analysis:

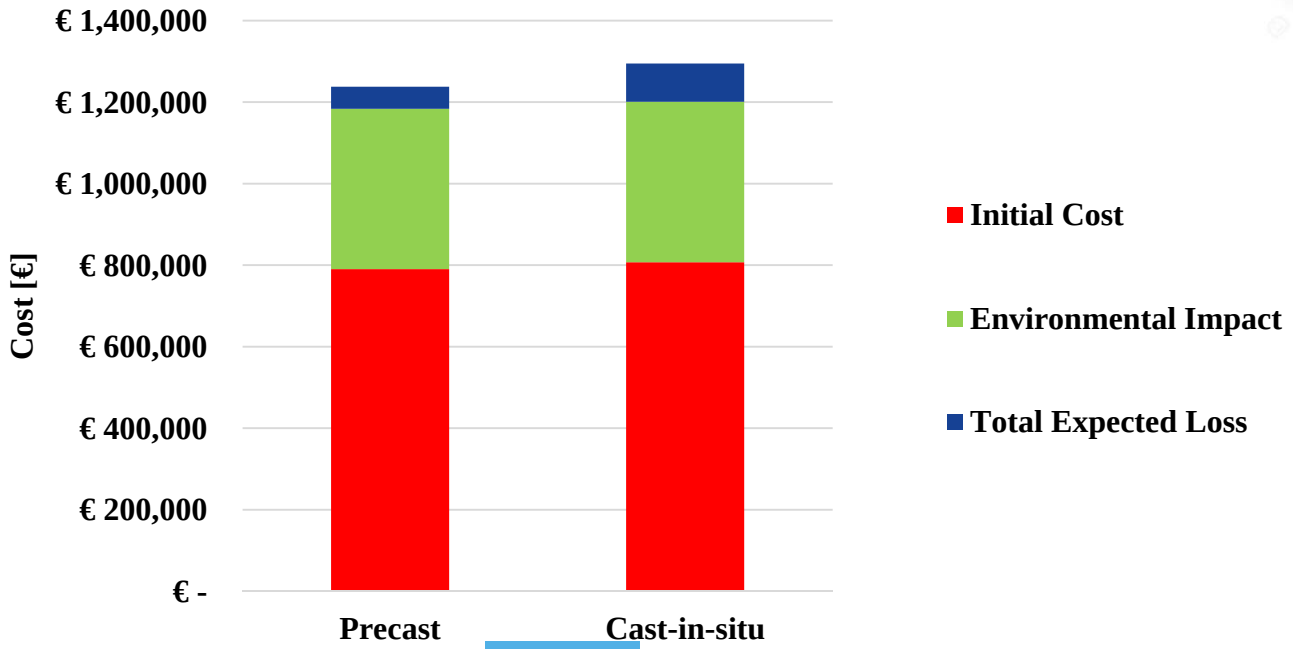
$$L = \sum_{i=1} C_i \cdot (R_i - R_{i+1})$$

Precast Structure						
Limit State	Drift [%]	PGA [g]	T_R [year]	R_{50} [%]	Damage cost [€]	Loss [€]
1	**0.75**	0.088	49.0	64.3	8318	3505
2	**1.50**	0.174	199.6	22.2	80216	9790
3	2.19	**0.250**	475.0	10.0	119743	8022
4	3.53	**0.400**	1489.5	3.3	988163	32631
					Total expected loss [€]	**53947**

Cast-in-situ Structure						
Limit State	Drift [%]	PGA [g]	T_R [year]	R_{50} [%]	Damage cost [€]	Loss [€]
1	**0.50**	0.045	30.0	81.6	9278	1750
2	**1.00**	0.090	51.1	62.8	92254	48692
3	2.79	**0.250**	475.0	10.0	148305	9935
4	5.15	**0.400**	1489.5	3.3	1008819	33313
					Total expected loss [€]	**93690**

Global Assessment Parameter

Cost [€]	Precast	Cast-in-situ
Initial Cost	790.530	807.055
Environmental Impact	393.218	394.054
Total Expected Loss	53.947	93.690
Global Assessment Parameter R_{SSD}	1.237.695	1.294.799



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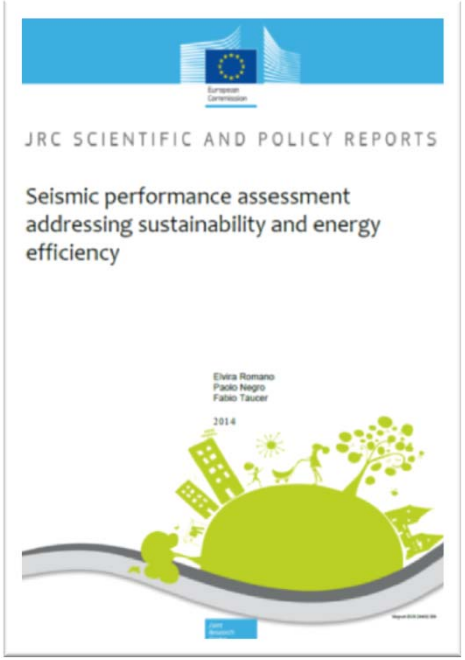
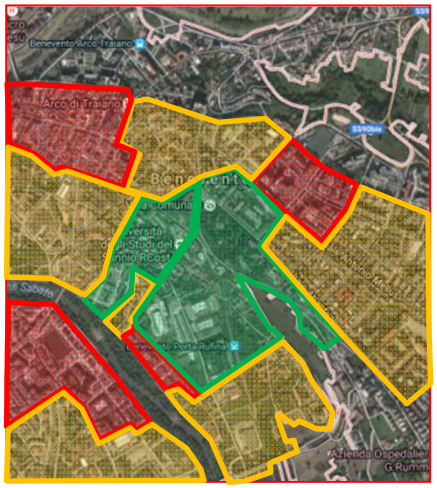
SAFESUST: combining safety and energy efficiency.



A single parameter to assess the performance of the intervention



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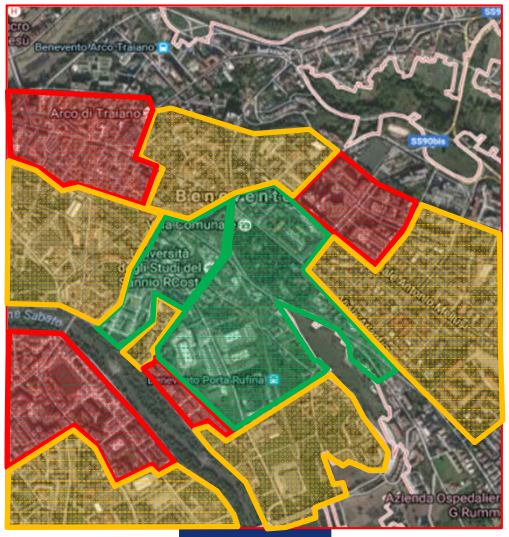
Development of the SSD Methodology

The methodology can be used at urban/regional/national level for **supporting stakeholders** in addressing **policy projects on the territory**

Linking all the buildings of a defined territory to **a single parameter** leads to identifying the areas where an intervention is more **urgent** and would be more **efficient**



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Not only earthquakes….

Structural safety
Higher live load requirements
Upgrading, transformations
Maintenance
Fire resistance

Damage to Ronan Point, 1968
Image credits: *Daily Telegraph*
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References

Guidelines for connections in precast structures:

http://doi.org/10.2777/37605

Guidelines for claddings:

http://doi.org/10.2788/546845

http://doi.org/10.2788/956612

Technical papers on precast structures/claddings:

https://link.springer.com/article/10.1007/s10518-013-9466-z

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http://dx.doi.org/10.1016/j.engstruct.2016.11.020

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http://doi.org/10.2788/338223

https://link.springer.com/article/10.1007/s10518-015-9845-8

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