



Integrated value model for sustainable assessment of school centers' construction

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Abstract: *Hundreds of new school centers were built in Catalonia between 2000 and 2009. It was a governmental decision in order to solve an endemic lack of centers that in the early 2000s had worsen. Masonry and poured on site reinforced concrete structures were used to build most of these schools as it had been done previously. The novelty was the use of interesting off site construction processes such as prefabricated concrete, steel and wood technologies. These school edifices and their building processes were analyzed in the author's thesis in 2009. Later in 2011 the author analyzed the lyfe cycle process of the construction of these centers. In this paper the authors assess the sustainability of these schools using a dynamic evaluation tool optimized for this case study. This tool has been defined using the Integrated Value Model for Sustainable Assessment (Modelo Integrado de Valor para una Evaluación Sostenible - MIVES).*

Keywords: *Sustainability, environmental impact, schools, construction*

1. Introduction

In the 2000s architects were still enlightened by magnificent examples of high-tech architecture from the 70s and 80s, such as the Centre Culturel d'Art Georges Pompidou in Paris designed by R. Piano & R. Rogers or N. Foster's Stansted Airport in London. Meanwhile, new critical theories were written about this architecture built using high-tech and prefabricated construction systems. In 2002, N. Sinopoli (2002) explained the importance of the building process management itself in terms of reducing frames. Later S. Kieran & J. Timberlake (2004) advised architects to leave a "century of failures" of off-site construction and join present's mass production with new icons such as airplanes industry. And C. Davies (2005) invited architects to learn from the anonymous prefabrication of mobile homes and bath pods instead of blindly following the celebrated high-tech architecture.

By then, new local exemplary architecture was built using off-site construction, taking advantage of its possibilities but without focusing the architectural expression or visual aspect in prefabrication itself. For example M. Ruisánchez & X. Vendrell's Riumar school of Deltebre in 1995 and P. Perez & M. Pàmies & A. Banús' Economic Faculty of Reus from 1994 to 1996. This architecture differed from all the schools previously badly built off-site, in the 60's in Europe & in the 70's in Spain. However, the educative community vividly remembered those previous experiences and was completely against using prefabricated systems to build schools. But the most important and active social opposition was against the intensive use of poorly conditioned prefabricated provisional modules ("barracaons") for public schools. From the 90s on more than 800 "barracaons" were used each year in order to solve an endemic lack of educational centers. This situation had worsen due to important

irregular unforeseen migratory movements, 1.000.000 people came from North Africa, South America and Eastern Europe while many families left cities to live in smaller villages.

Finally, in 2002 the government decided to build hundreds of new school centers to solve this severe lack of schools. These new schools were built following tight frames and, therefore, the contractual process was necessarily simplified. However, each school had an individual architectural design in which the future educational team was invited to participate. But the tight frames and low budgets minor the social and environmental aspects of the designs.

This research paper exposes a sustainability assessment of these schools. This assessment was presented in [Pons et al., 2012](#).

2. School buildings and their construction processes

This research considers a sample of 384 preschool and elementary public school edifices built from 2002 to 2009 in Catalonia. This sample was previously studied in the author's thesis ([Pons, 2009](#)) concluding that these educational buildings had been designed following strict standards from the government. These standards determined their surface area (6 to 7 m²/ student), their spaces (number and type of classrooms, gymnasium, dining room, offices, etc.), their volumetry (rectangular 3 storey elementary building, a single storey U-shaped preschool edifice, rectangular 4,5 m high gym building, etc.). In consequence, these school edifices could be rigorously studied by classifying them according to the technologies used to build them. In [Table 1](#) and [Fig. 1](#) there is this classification and the use of these technologies to build these 384 schools respectively. Both show that most schools were built using poured on site reinforced concrete structures and less using concrete, steel and timber off-site structures.

Process	Structural material	Structural typology	Percentage of schools (%)
On site technologies	Structural Concrete	Frames	58,0
		Columns and slabs	
Prefabricated technologies	Structural Concrete	Frames	22,7
		Load-bearing walls	
		Load-bearing room modules	
	Structural steel	Load-bearing walls & modules	19,0
		Frames	
	Structural timber	Load-bearing room modules	0,3
Load-bearing walls			
		Load-bearing walls & modules	

Table 1. Classification of the technologies used to build these 384 school centers.

This study will focus on the technologies used to build most of the school's structures which are: the onsite concrete structure technology (OC); the prefabricated concrete framed structure technology (PC), and the prefabricated steel modules structure technology (PS). This research project also studies the prefabricated timber structure system (PT) because, although having been less used, it is based on a different material with an outstanding environmental behavior.

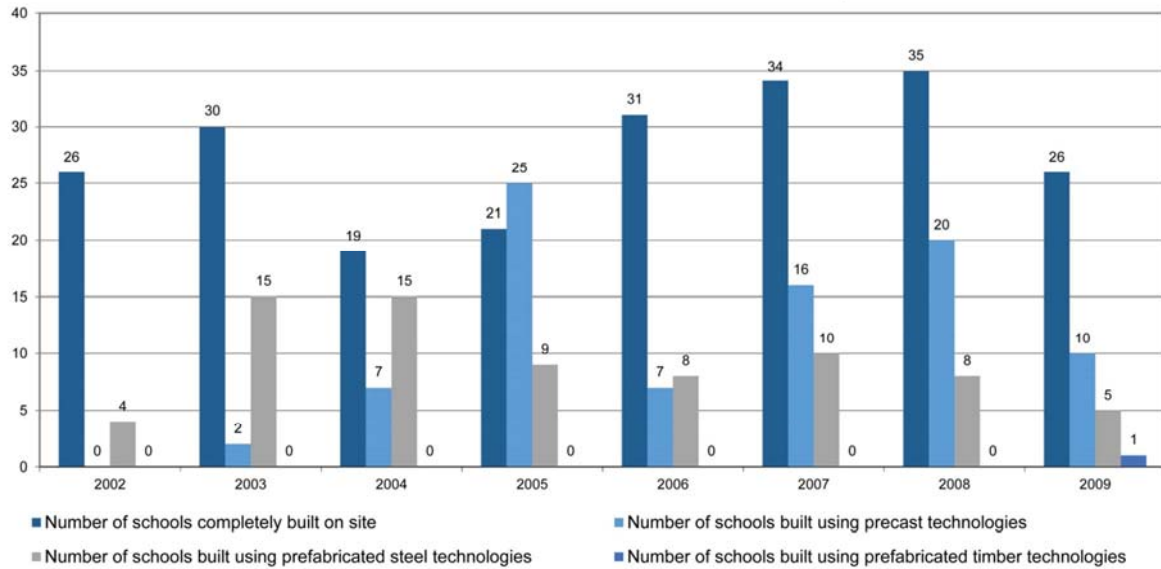


Figure 1. Number of schools built using on site and prefabricated concrete, steel and timber technologies.

Educational centers build using OC have a poured in situ reinforced concrete hyperstatic structure, which is either bidirectional – with columns and waffle slabs – or unidirectional – with frames and ribbed floors. Columns have square sections from 30 x 30 to 40 x 40 cm and distant one to the other up to 7 m. Floors can either have a uniform height of 30 cm or be 25 cm high with beams 45 cm high. Schools constructed utilizing PC have a prefabricated reinforced concrete isostatic unidirectional structure composed of frames and hollow core slabs. Frames have continuous columns each 6 m maximum, with orthogonal cross sections from 40 x 40 m to 60 x 60 m. Beams have the columns base; up to 40 cm of its height is precast and visible while the other part is embedded in the floor, which has a topping layer poured on top of the hollow core slabs and beams. Slabs are 16 to 40 cm wide and they span up to 12 m.

Educational centers build using PS are composed of steel room modules with a maximum size of 3.2 x 3.65 x 18.4 m. These modules have square hollow section columns – for example 140.140.6 – welded to hot-rolled section beams – UPN 270 – which contain a composite slab – for example 12 cm wide. Schools built utilizing PT have a timber structure composed of structural walls, load bearing room modules and slabs. Walls are 57 to 158 mm wide massive laminated timber panels whose area measures 2.95 x 16.5 m maximum. Room modules have several of these structural walls and one or two slabs. Floor slabs are 60 to 248 mm wide laminated timber also 2.95 x 16.5 m maximum.

3. Analysis

Researchers aimed to find the building technology which had the lowest environmental, economic and social impact in the construction of hundreds of preschool and elementary centers. To do so there was the possibility of using an existing tool so the best tools to assess the object of study were analysed – BREEAM, CASBEE, DGNB-Seal, EcoEffect, Green

Globes, Green Star, HQE, BEAM, LEED, VERDE. To analyse them the researchers took into account previous reviews and if the tool: was complete and included environmental, economic and social indicators, if it was possible to assess school buildings, etc. These 13 tools and their predecessors have contributed to move forward to a more sustainable architecture. They have brought methodology and they have contributed to raise awareness in the construction sector, but their influence mainly bears on the need to reduce the environmental impact.

3.1. Sustainability assessment of the case study

Following the results of this analysis of assessment tools, the researchers decided to use a new tool based on the Integrated Value Model for Sustainable Assessment (MIVES), which is a Multi-Criteria Decision Making Method that has already been applied to several areas, such as the Spanish structural concrete standards (Aguado et al. 2013). MIVES was chosen mainly because it permitted fast assessments for edifices with tight timeframes, such as the schools of this sample.

Following MIVES, the decision making tree in [Table 2](#) was built, which includes only the main and the most discriminatory indicators, so it is adequate to obtain a correct assessment decision because indicator amount is not excessive.

Requirements	Criteria (%)	Indicators
R1. Economic (50%)	C1. Cost (52%)	I1. Production and assembly cost (30%) I2. Cost deviation probability (25%) I3. Maintenance cost (45%)
	C2. Time (48%)	I4. Production and assembly timeframe (38%) I5. Timeframe deviation probability (62%)
R2. Environmental (30%)	C3. Phase 1: extraction and fabrication of materials (30%)	I6. Water consumption (22%) I7. CO ₂ emissions (40%) I8. Energy consumption (38%)
	C4. Phase 2: transport (10%)	I9. CO ₂ emissions (100%)
	C5. Phase 3: building and assembly (15%)	I10. CO ₂ emissions (58%) I11. Solid waste (42%)
	C6. Phase 4: use and maintenance (30%)	I12. CO ₂ emissions (100%)
	C7. Phase 5: end of life (15%)	I13. Solid waste (100%)
R3. Social (20%)	C8. Adaptability to changes (35%)	I14. Neither adaptable nor disassemble building percentage (theoretical) (50%) I15. Deviation of neither adaptable nor disassemble building percentage (50%)
	C9. Users' safety (65%)	I16. Labor risk of accidents (40%) I17. Users risk of accidents (60%)

Table 2. Decision making tree for the sustainability assessment of the studied schools.



Economic requirement includes 5 indicators which evaluate: construction and maintenance cost over 50 years, construction timeframes and the probability of deviation in both. The cost of school edifices usage is not taken into account because it is not discriminatory. The end of life cost has not been included either because it is considered account in the environmental indicator I13. The environmental requirement considers 5 LCA phases: 1) extraction and production; 2) transport; 3) construction and assembly; 4) use and maintenance over 50 years; 5) end of life. This requirement is based on a simplified LCA about these 4 technologies (Pons et al 2011) that from the 5 life cycle phases studies 4 indicators: CO₂ emissions, energy consumption, water consumption and solid waste production. Only the most important and discriminatory indicators for each phase are considered. For example, water consumption during the construction and assembly phase is not included because, in the most unfavorable case, it is less than 0.01% of the whole life cycle water consumption. Social requirement includes 4 indicators which assess: technologies capacity to disassemble and change their parts during the school building's usage and this capacity probability of deviation; construction and assembly accident risk. Some social indicators have been not included because they were not discriminatory, such as the ease to enlarge edifices or the industry workers' safety.

These 3 requirements, 9 criteria, 17 indicators and their weights (λ_i) were decided during various seminars of experts. A value function (Alarcón et al) was designed for each indicator, relying on numerous and rigorous bibliography. Although the 17 indicators have different units, all their value functions vary from 0 to 1, 0 being the minimum satisfaction and 1 the maximum satisfaction for each indicator. These adimensional values $V_i(x_i)$ can be aggregated in order to obtain the global sustainability index V from [equation 1](#).

$$V = \sum \lambda_i \cdot V_i(x_i) \quad [1]$$

These 17 value functions depend on 5 parameters, as shown in [equation 2](#). These parameters define its shape and therefore how each indicator value variation is translated to the adimensional scale. Then, if the function shape is an S, then the initial and final indicator value variation will have an adimensional value variation smaller than the middle value variation.

$$V_{ind} = A + B \cdot \left[1 - e^{-ki \cdot \left(\frac{|X_{alt} - X_{max}|}{C_i} \right)^{Pi}} \right] \quad [2]$$

In [equation 2](#), A is the response value Xmax (indicator's abscissa), and Xalt is the assessed indicator abscissa which gives a value Vind. Pi is a shape factor that determines if the curve is concave, convex or shaped as a "S". Ci establishes, in curves with Pi>1, abscissa's value for the inflexion point. Ki defines the response value to Ci. B is the value that keeps the function in the range from 0 to 1 and it is defined in equation 3.

$$B = \left[1 - e^{-ki \left(\frac{|X_{\max} - X_{\min}|}{C_i} \right)^{p_i}} \right]^{-1} \quad [3]$$

From the 17 value functions, 8 decrease convexly (CvxD), 5 decrease lineally (SD) and 4 decrease concavely (CcvD). Convex functions are for indicators which the administration accepts a partial satisfaction, such as: construction timeframes, environmental indicators... On the other hand, concave functions represent indicators which the administration demands a maximum value, such as safety. Decreasing functions have 0 as the most satisfactory value and take the worst value of the studied systems as the least satisfactory.

4. Results and discussion

Assessing the four main technologies used to build the schools of the sample using the aforementioned MIVES tool we obtain their sustainability indexes, which are shown in [Table 3](#) and are applicable to the schools in this sample. These indexes show that these technologies could improve in the following way:

- Precast concrete system ought to improve: environmental indicators mainly from phase 1 extraction and production; and social indicators, firstly its low adaptability and reversibility.
- Prefabricated steel technology should improve: environmental indicators from phase 1 and from phase 2, reducing the distance from site to factory; and ought to reduce the distance from site to industry.
- Wood technology should improve: environmental indicators from phase 2 and economic indicators such its durability and maintenance.
- On site concrete system should improve most of its indicators: economic (timeframes, etc.), environmental (construction waste, etc.) and social indicators (flexibility and risk of accidents).

Technology	Requirement			Global index	Application (%)	Sustainability
	Economic	Environmental	Social			
PC	0.83	0.64	0.55	0.72	22,7	Major
PS	0.81	0.51	0.78	0.71	19,0	
PT	0.53	0.58	0.73	0.59	0,3	
OC	0.38	0.41	0.17	0.35	58,0	Minor

Table 3. Sustainability indexes of the building technologies used to construct the schools of the sample.

The application of these 4 construction technologies to build the schools of the sample does not respond to sustainability index, because these schools were built without considering sustainability criteria. Studying the sustainability assessment results relying on rigorous an extended studies about these schools (Pons 2009) we can conclude that the application of these systems depended on three factors: a) political, social and technical rejection of



prefabricated technologies; b) factory and contractor productive and executive capacity and c) a recently implemented PT system.

5. Conclusions

The sustainability assessment tool defined in this research project is specialized for the sample; quick; takes into account applying this technology in the architectural design process and in the finished school; gives both global and partial detached indexes. The authors consider that this methodology could be able to assess similar samples if previously reconfigured.

To build these sample educational centers: a) prefabricated concrete and steel processes are the most sustainable; b) the wood technology applied has an unexpectedly low index, being an exemplar building system that, for this object of study in which the production center is remote (1600 km), is not the best option; c) on site concrete building process is the least sustainable process and should be improved before using it again. Therefore, this investigation project's results are different and new from previous sustainability assessments on prefabricated technologies.

This investigation could be used so that in the near future educational centers would be constructed following sustainability reasons. The application of the tool defined in this study could result in having better future school centers.

6. References

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