Trasferimento tecnologico e metodologie evolutive dei sistemi costruttivi

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Abstract. Lo studio esamina gli orientamenti teorico-metodologici (intrapresi dal *Technology Research & Development Office,* nell'esercizio di Terza Missione) diretti alle pratiche di "sostituzione tecnologica" e di "ri-configurazione tipologica" dei sistemi costruttivi. L'approccio metodologico contempla le tecniche di trasformazione incrementale rivolte alla gestione/riduzione della complessità, a supporto sia degli *Architectural Engineering Services*, sia dei *Systems Manufacturing Stakeholders*. La tesi propone l'elaborazione di un metodo di valutazione inteso a determinare sia l'efficacia tecnico-economica e temporale delle procedure di evoluzione sistemica, sia i potenziali sviluppi di trasferimento calibrato dalle prassi proprie di *Topology Optimization* e di *Advanced Manufacturing*.

Parole chiave: Progettazione tecnologica e ambientale; Trasferimento tecnologico; *Implementation design*; *Design for assembly and manufacturing*; Sistemi costruttivi evoluti.

Obiettivi: pratiche evolute di gestione/riduzione della complessità dei sistemi costruttivi

Lo studio si inserisce all'interno del *background* scientifico della Progettazione Tecnologica e Ambientale, correlato alle teorie sulla Transizione Tecnologica (Ragulina, 2019) e declinato nei processi di "trasformazione adattiva", di "sostituzione tecnologica" e di "ri-configurazione tipologica" dei sistemi costruttivi (Swilling, 2020). Gli obiettivi riguardano gli orientamenti diretti alla gestione/riduzione della complessità nei processi progettuale, produttivo e costruttivo, concentrati sulle metodologie evolutive dei sistemi costruttivi. Lo studio contempla, quale apporto alle pratiche di trasferimento tecnologico verso le potenzialità/criticità e necessità/prospettive di innovazione, la trattazione delle attività svolte dal *Technology Research & Development Office*: questa intesa quale struttura multidisciplinare e interna alla particolare Unità Sperimentale Dipartimentale (di tipologia "*hard*", che sostiene le linee strategiche di ricerca), impegnata nell'esercizio di Terza Missione. Gli orientamenti metodologici assumono le azioni progettuali (come esercizio di *heuristic modelling design*, di *project efficiency consulting* e di *detailed/executive processing*) a supporto di specifici categorie di *stakeholders*, che necessitano di aumentare o di specializzare il proprio *know-how* in funzione delle variate condizioni e/o di inserimento in nuovi contesti di mercato, dei rinnovati assetti normativi, di partecipazione a progetti sottoposti a requisiti di ottimizzazione produttiva/costruttiva (Benneworth *et al*., 2015). Le azioni da parte del *Technology Research & Development Office* sono orientate a:

- gli *Architectural Engineering Services*, quali comparti di progettazione integrata impegnati nella formulazione di soluzioni tecnico-economico evolute (con l'attivazione di *cost-effective solutions*), nella razionalizzazione processuale (secondo criteri di anticipazione, simulazione e modellazione previsionale) e nelle modalità di *sustainable design* riferite al contenimento dei consumi (energetici, materici) e degli impatti ambientali;
- i *Systems Manufacturing Stakeholders*, quali operatori afferenti al settore produttivo, focalizzati sull'accrescimento prestazionale e commerciale di sistemi, componenti e/o elementi tecnici, e al settore costruttivo (nei modi di *off-site manufacturing*; Hu *et al*., 2019), protesi alla riduzione dei costi di capitale (secondo i principi di *design-to-target value*), all'ottimizzazione gestionale/organizzativa e al controllo (qualitativo) delle lavorazioni (Conti and Grimaldi, 2024).

Technology transfer and advanced methodologies of building systems

Abstract. The study examines the theoretical-methodological approaches (undertaken by the Technology Research & Development Office, in the Third Mission exercise) directed towards the practices of "technological substitution" and "typological re-configuration" of building systems. The methodological process involves incremental transformation techniques aimed at controlling and reducing complexity, supporting both Architectural Engineering Services and Systems Manufacturing Stakeholders. The thesis aims to provide an evaluation method to determine the technical, economic and time effectiveness of systemic evolution procedures, as well as potential transfer developments calibrated by the practices of Topology Optimisation and Advanced Manufacturing.

Keywords: Technological and environmental design; Technology transfer; Implementation design; Design for assembly and manufacturing; Advanced building systems.

Purposes: advanced control/complexity reduction practices for building systems

The study is carried out within the scientific background of technological and environmental design related to the theories of technological transition (Ragulina, 2019), and developed in the processes of "adaptive transformation", "technological substitution" and "typology re-configuration" of building systems (Swilling, 2020). The purposes concern approaches oriented to control/reduce complexity in design, production and construction processes, focusing on evolution methods of building systems. As a contribution to technology transfer practices towards innovation potential/criticalities and needs/perspectives, the study envisages a discussion of activities carried out by the Technology Research & Development Office. This is intended as a multidisciplinary structure within the particular Department Experimental Unit (the "hard" type, which supports strategic research lines) engaged in the Third Mission exercise. The methodological approaches take on project actions (as an exercise in heuristic modelling design, project efficiency consulting and detailed/executive processing) to support specific categories of stakeholders, which need to increase or specialise their know-how according to changing conditions and/or inclusion in new market contexts, renewed normative frameworks, and participation in projects subject to production/construction optimisation requirements (Benneworth *et al*., 2015). The

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Approccio metodologico: analisi delle procedure di trasformazione incrementale dei sistemi costruttivi

L'approccio metodologico contempla la rilevazione dell'impianto cognitivo e delle pratiche di trasformazione tecnologica e di trasferimento incrementale rivolte alla gestione/riduzione della complessità dei sistemi costruttivi di tipo tradizionale. Queste pratiche, teorizzate e applicate da parte del *Technology Research & Development Office* a supporto degli *Architectural Engineering Services e dei Systems Manufacturing Stakeholders*, sono trasposte attraverso l'adozione dei processi di *technology-rationalized design* per la "mutazione progressiva" dei sistemi costruttivi (in modo diverso dalla loro "re/invenzione") (Kwok *et al*., 2023). L'approccio metodologico si sviluppa attraverso l'analisi de:

1. le attività di *implementation design* (Wise and Vytasek, 2017), correlate ai modi di *conceptual information design* (Pontis, 2021) e al paradigma di *Reconfigurable Manufacturing System* (Najid *et al*., 2020), che comportano la fase di modellazione esecutiva (dei sistemi costruttivi tradizionali) e, poi, la fase di "prototipazione cognitiva ottimizzata" (identificata come *processing prototype*, ovvero come trasformazione tecnologica in forma incrementale e progressiva). Le attività di *implementation design* prevedono la concezione di modelli di stima, finalizzati a limitare le risorse materiali, economiche e temporali, caratterizzati da processi euristici e abduttivi che associano:
   – la razionalizzazione tipologica e quantitativa sia dei cicli sia dei costi di lavorazione, in accordo alle strategie di *Design for Assembly and Manufacturing*, basate sui criteri di pre-assemblaggio, sulla sequenzialità esecutiva, sulla risoluzione delle interfacce critiche e sulle tecniche di simulazione produttiva/costruttiva (Tan *et al*., 2020; Laovisutthichai and Lu, 2021);
   – la pianificazione, semplificazione e standardizzazione dei modi di installazione, di riduzione dei tempi e dei dispositivi di montaggio *on-site*, in accordo ai *Modern Methods of Construction* (Hyun *et al*., 2022; Roxas *et al*., 2023);
2. la determinazione del metodo di valutazione (sperimentale) inteso a comprendere la soglia dell'efficacia tecnico-economica e temporale dei risultati conseguenti alle attività di *implementation design*, rivolte alla trasformazione tecnologica e al trasferimento incrementale delle soluzioni sistemiche e costruttive tradizionali;
3. la rilevazione delle conseguenti opportunità/potenzialità di evoluzione funzionale, produttiva e ambientale dei sistemi costruttivi (o di loro parti) attraverso l'integrazione di forme successive di *Topology Optimization* e di *Advanced Manufacturing* (Donofrio, 2016; Cool *et al*., 2025).

Tesi proposta: modellazione valutativa per lo sviluppo ottimizzato dei sistemi costruttivi

La tesi assume gli orientamenti di trasformazione tecnologica diretti alla gestione/riduzione della complessità come procedimento di *implementation design*, che contempla:

1. l'indicazione/selezione/sottomissione del sistema costruttivo da parte dello *stakeholder* al Technology Research & Development Office, che viene sottoposto alla elaborazione

activities of the Technology Research & Development Office focus on:
– Architectural Engineering Services, as integrated design sectors engaged in the formulation of advanced technical-economic solutions (with the activation of cost-effective solutions), in the rationalisation of processes (according to the criteria of anticipation, simulation and predictive modelling), and in sustainable design methods referring to the reduction of consumption (energy, materials) and environmental impact;
– System Manufacturing Stakeholders, as operators involved in the production sector, addressing the performance and commercial improvement of systems, components and/or technical elements, and in the construction sector (in off-site manufacturing modes; Hu, *et al*., 2019), aimed at capital cost reduction (according to design-to-target value principles), management/organisational optimisation and (quality) control of fabrication (Conti and Grimaldi, 2024).

Methodological approach: analysis of incremental transformation processes of building systems

The methodological approach implies the detection of cognitive frameworks and practices of technological transformation and incremental transfer aimed at controlling/reducing the complexity of traditional building systems. Theorised and applied by the Technology Research & Development Office in support of Architectural Engineering Services and Systems Manufacturing Stakeholders, these practices are implemented through the adoption of technology-rationalised design processes for the "progressive mutation" of building systems (as opposed to their "re-invention"; Kwok, *et al*., 2023). The methodological approach is developed by:

1. analysing the implementation design activities (Wise and Vytasek, 2017) related to the conceptual information design modes (Pontis, 2021) and the Reconfigurable Manufacturing System paradigm (Najid *et al*., 2020), which include the executive modelling phase (of traditional building systems), and then the "optimised cognitive prototyping" phase (identified as a processing prototype, *i.e.* technological transformation in an incremental and progressive form). The implementation design activities involve the conception of estimate models aimed at limiting material, economic and time resources, characterised by heuristic and abductive processes that combine:
   – the typology and quantitative rationalisation of both cycles and fabrication costs, in accordance with Design for Assembly and Manufacturing strategies, based on pre-assembly criteria, executive sequences, resolution of critical interfaces and production/construction simulation techniques (Tan *et al*., 2020; Laovisutthichai and Lu, 2021);
   – the planning, simplification and standardisation of installation methods, time reduction and on-site assembly devices according to Modern Construction Methods (Hyun *et al.* 2022; Roxas *et al*., 2023);
2. determining the (experimental) evaluation method to understand the threshold of technical-economic

preliminare in forma di unità geometrico-dimensionale, funzionale e produttiva/costruttiva: questo considerando, come caso di studio sperimentale ed esemplificativo, un sistema di involucro/rivestimento reale (Montali *et al.*, 2017; Wasim *et al.*, 2020);
2. la fase di modellazione esecutiva del sistema costruttivo, rispetto al quale sono individuate le potenziali azioni progettuali di "sostituzione tecnologica" e di "ri-configurazione tipologica" mediante l'applicazione de:
   - i *Technical Hybridization Processes* e gli *Integrated Multi-Functional Systems*, secondo la "trasmutazione fisica" dei componenti, dei modi di assemblaggio e la combinazione di "composti prestazionali";
   - i principi di *Environmental Conscious Design*, secondo l'ausilio di prodotti a basso impatto ambientale, la conversione degli apparati massivi portanti con intelaiature/orditure caratterizzate da elevata resistenza meccanica, componibilità e adattabilità, i metodi di semplificazione esecutiva e di riparazione/smontaggio/sostituzione (Fig. 1);
3. la fase di "prototipazione cognitiva ottimizzata", secondo il metodo teso all'"evoluzione progressiva" e graduale del sistema costruttivo (trasferibile a molteplici ambiti, evitando l'eccessiva trasformazione fisica e materica che può condurre a divergenze valutative oltre che incisive verso altri sistemi). Questa fase si concreta quale esito del processo di riduzione della complessità componentistica e connettiva, nel mantenimento dei contenuti geometrico-dimensionali, morfologici e funzionali del sistema tradizionale (Fig. 2);
4. la fase di *evaluating prototype*, che riguarda l'analisi degli output emergenti sia dalla comparazione sia dall'interpolazione dei dati riferiti alla costituzione esecutiva e alla simultanea valutazione estimativa dei costi unitari per elemento/materiale (posato in opera), dei tempi unitari di costruzione e delle principali attrezzature di cantiere. La fase di valutazione permette di analizzare/acquisire, in termini di fattibilità, le situazioni di allineamento o di scostamento tra il modello esecutivo e il "prototipo cognitivo ottimizzato". Nel caso di studio sperimentale ed esemplificativo, riferito al sistema di involucro/rivestimento reale, emerge la situazione di scostamento risultante da:
   - l'incremento del costo unitario di costruzione del "prototipo cognitivo ottimizzato" rispetto al modello esecutivo tradizionale pari all'85,54%;
   - la riduzione dei tempi unitari di costruzione del "prototipo cognitivo ottimizzato" (rilevando l'esecuzione simultanea tra la quasi totalità dei moduli opachi e del modulo trasparente) rispetto al modello esecutivo tradizionale pari all'85,41% (Figg. 3, 4).

La tesi prosegue con la valutazione dell'efficacia delle procedure di "sostituzione tecnologica" e di "ri-configurazione tipologica" (secondo gli input applicati nella fase di *processing prototype* e gli output emersi dalla fase di *evaluating prototype*). L'efficacia delle pratiche in esame, quantificabile rispetto alla riduzione dei costi di capitale (attraverso lo studio sperimentale e la situazione di scostamento degli output), è stimata mediante la formulazione originale del "modello (analitico-metodologico) interattivo" che consente:
1. l'interpolazione tra i parametri e le metriche di valutazione, attraverso:
   - l'utilizzo della potenziale "quantità applicativa" (nel mo-

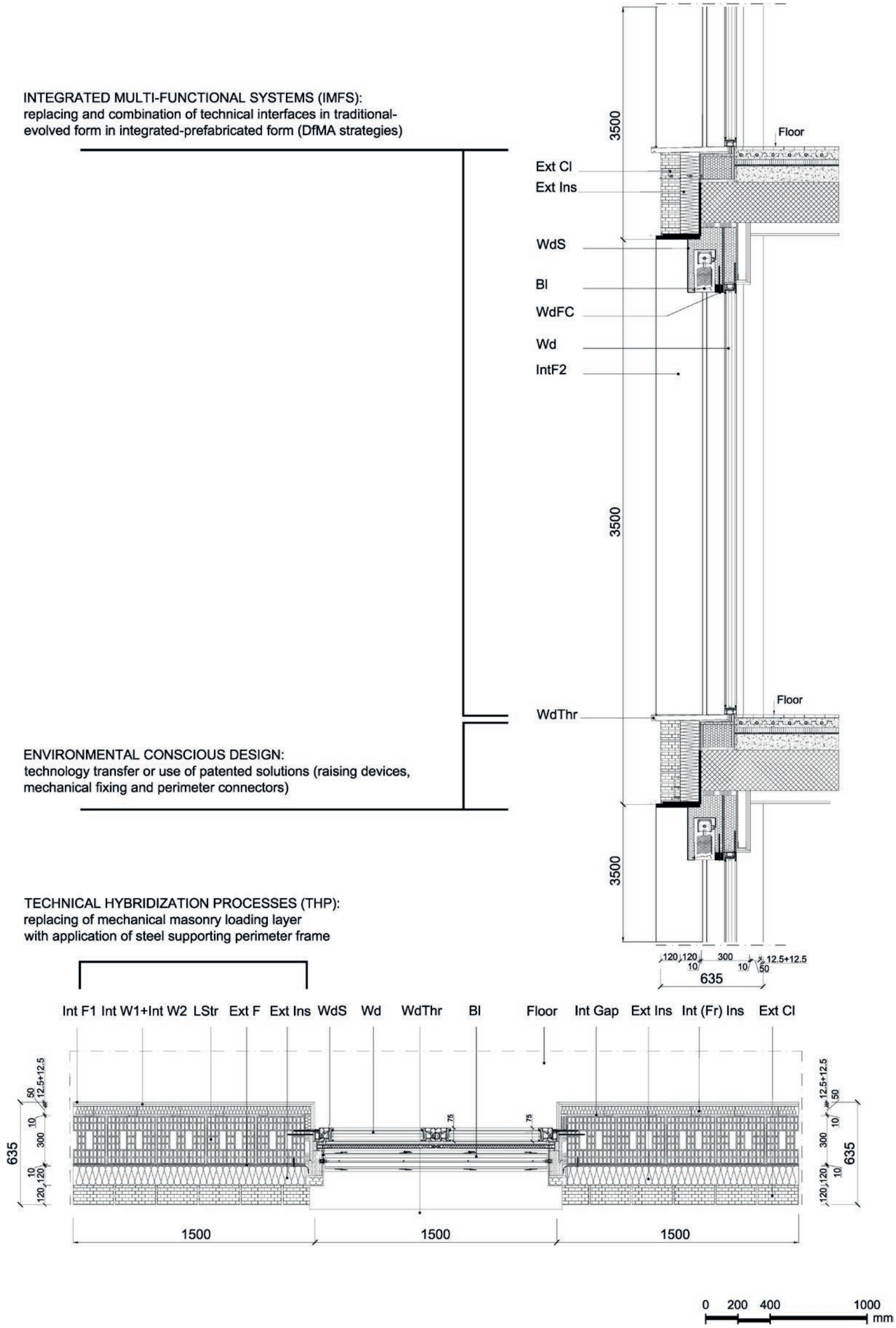
and temporal effectiveness of results emerging from *implementation design* activities aimed at technological transformation and incremental transfer of traditional systemic and construction solutions;
3. detecting subsequent opportunities/potential for functional, productive and environmental evolution of building systems (or parts thereof) through the integration of successive forms of Topology Optimisation and Advanced Manufacturing (Donofrio, 2016; Cool *et al.*, 2025).

Thesis proposal: evaluative modelling for the optimised development of building systems

The thesis assumes the technological transformation approaches directed towards controlling/reducing complexity as an implementation design procedure, which contemplates:
1. the indication/selection/submission of the building system by the stakeholder to the Technology Research & Development Office. The project is subjected to preliminary processing in the form of a geometric-dimensional, functional and productive/constructive unit, considering, as an experimental and exemplifying case study, a real envelope/cladding system (Montali *et al.*, 2017; Wasim *et al.*, 2020);
2. the executive modelling phase of the building system, in relation to which the potential design actions of "technological substitution" and "typological re-configuration" are identified through the application of:
   - Technical Hybridisation processes and Integrated Multi-Functional Systems, according to the "physical transformation" of components, assembly modalities and the combination of "performance compounds";
   - the principles of Environmental Conscious Design, based on the use of products with a low eco-impact, the conversion of massive load-bearing supports with frames/edges characterised by high mechanical resistance, modularity and adaptability, the methods of simplification and repairing/disassembly/replacement (Fig. 1);
3. the "optimised cognitive prototyping" phase, in accordance with the method aimed at the "progressive evolution" and successive development of the building system (transferable to multiple fields, avoiding excessive physical and material transformation, which can lead to divergences in evaluation, while impacting other systems). This phase is the result of a process reducing the complexity of components and connections, while maintaining the geometric-dimensional, morphological and functional content of the traditional system (Fig. 2);
4. the evaluating prototype phase, which involves analysing the results of both the comparison and interpolation of data concerning the executive constitution and the simultaneous estimation of the unit costs per element/material (built in), the unit construction times and the main on-site tools. The evaluation phase allows analysis/acquisition, in terms of feasibility, of situations of alignment or divergence between the executive model and the "optimised cognitive prototype". In the experimental and exemplifying case study, referring to the real envelope/cladding

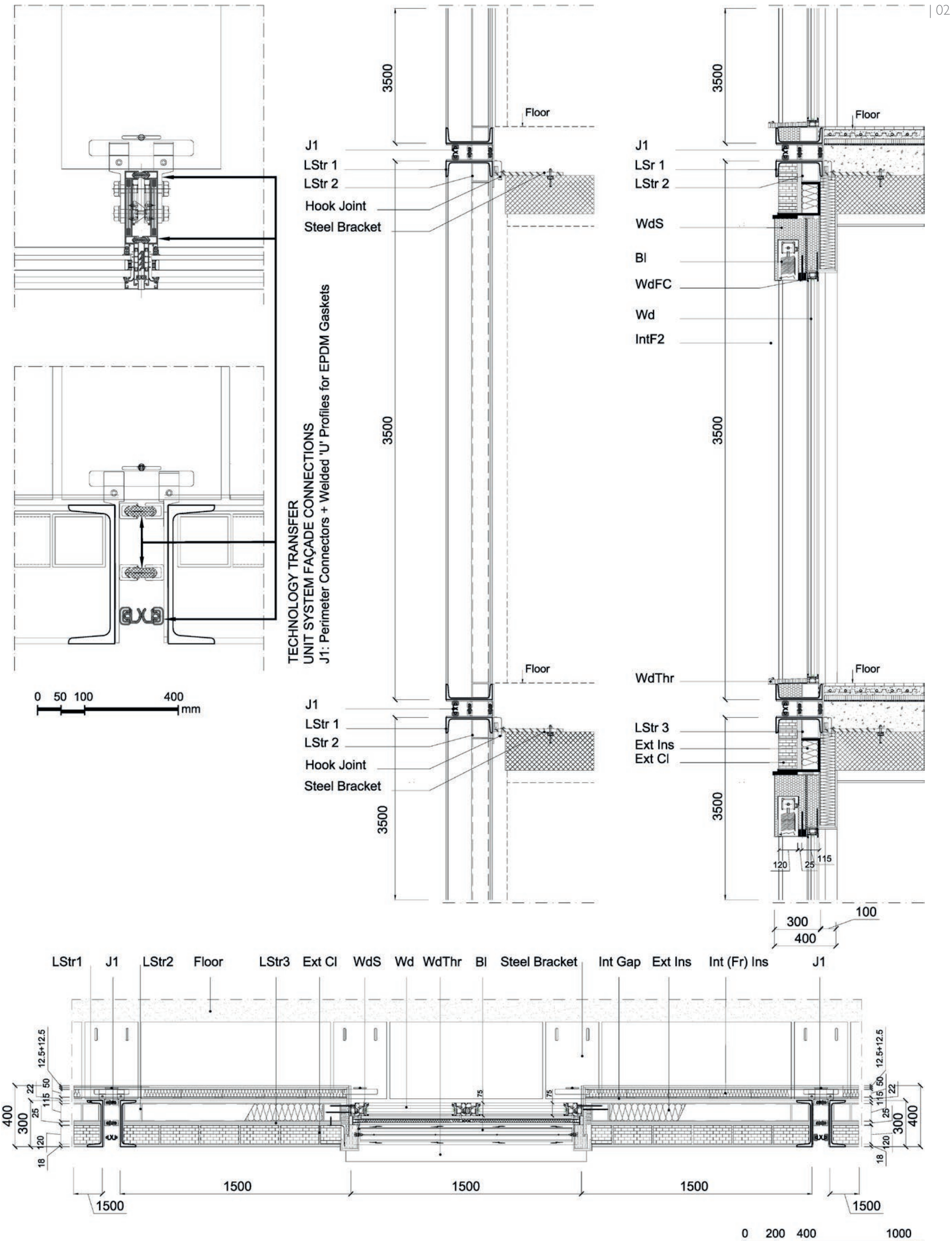
01 | Modellazione esecutiva di sistema costruttivo tradizionale, Autore e Fabio Grossi (Smart Manufacturer, SMV Costruzioni s.r.l.)
Executive modelling of traditional building system, Author and Fabio Grossi (Smart Manufacturer, SMV Costruzioni s.r.l.)

01 |

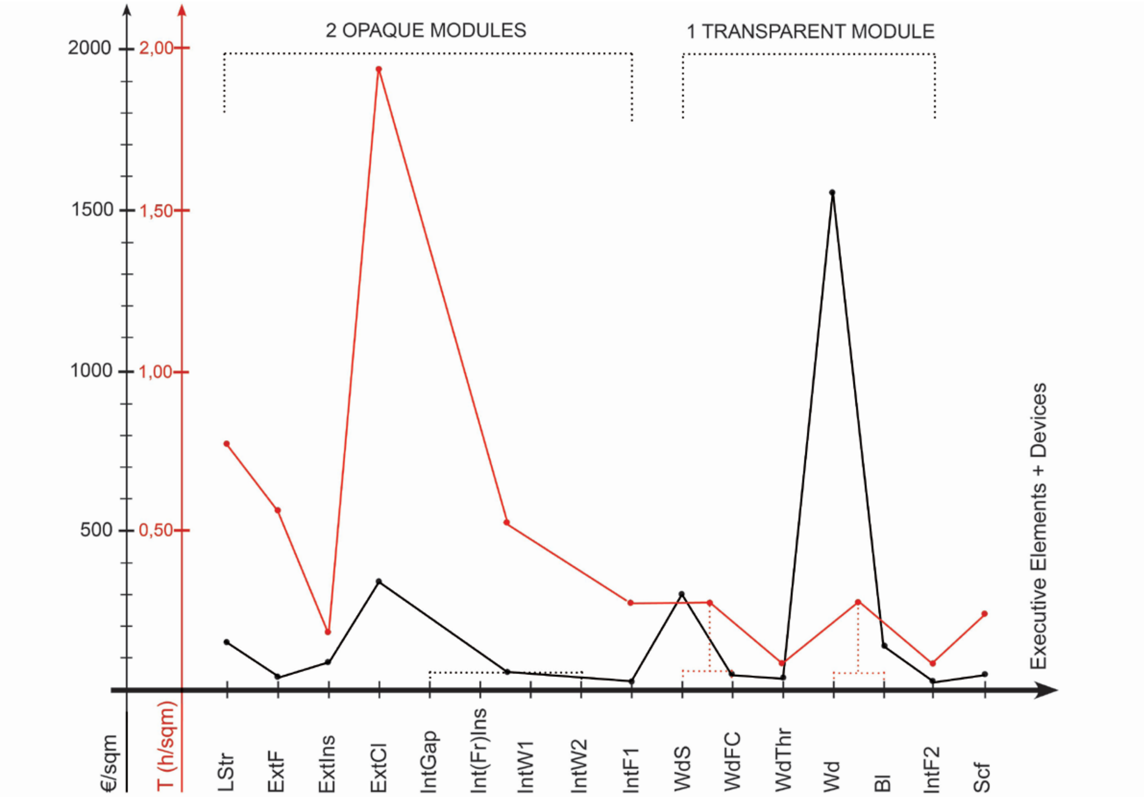


02 | "Prototipazione cognitiva ottimizzata" di sistema costruttivo sottoposto a trasformazione incrementale, Autore e Fabio Grossi (Smart Manufacturer, SMV Costruzioni)

"Optimised cognitive prototyping" of building system subjected to incremental transformation, Author and Fabio Grossi (Smart Manufacturer, SMV Costruzioni s.r.l.)



03 |



2 OPAQUE MODULES
(b = 1,50 m; h = 3,50 m) × 2; S_{tot} = 10,50 sqm

Code	Elements	mm	€/sqm	h	h/sqm
LStr	Wall Structure Poroton Blocks	300	115,00	8	0,76
ExtF	Ext. Finishing Plaster	10	32,00	6	0,57
ExtIns	Ext. Insulation XPS/EPS	120	95,00	4	0,38
ExtCl	Ext. Cladding Brick Blocks Cement Glue Steel Bracket	120	345,00	20	1,90
IntGap	Air Gap	10	75,00	6	0,57
Int(Fr)Ins	Steel Framing Rockwool	50			
IntW1	Int. Counterwall Fbr Plasterboard	12,5			
IntW2	Int. Counterwall Plasterboard	12,5			
IntF1	Int. Finishing	0	10,50	3	0,29
		635	**672,50**	**38**	**3,62**
2 opaque modules cost (€)			**7.061,25**		

1 TRANSPARENT MODULE
(b = 1,50 m; h = 3,50 m) × 1; S_{tot} = 5,25 sqm

Code	Elements	mm	€/sqm	h	h/sqm
WdS	Integr. Window System	560	310,00	3	0,57
WdFC	False Ceiling		45,00		
WdThr	Threshold		25,00	1	0,19
Wd	Window Thermal Cut All. Framing Open. Panel Double Glazing	75	1.550,00	2	0,38
Bl	Blind	10	135,00		
IntF2	Int. Finishing		20,00	1	19
		645	**2.085,00**	**7**	**1,33**
1 transparent module cost (€)			**10.946,25**		

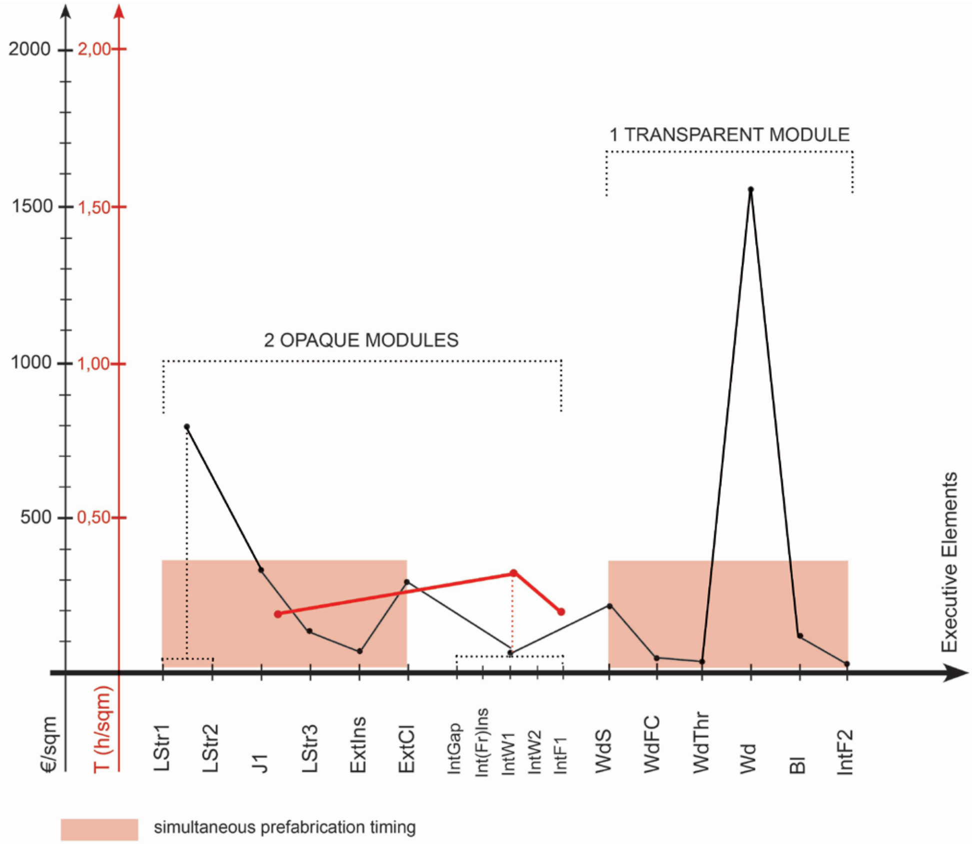
2 OPAQUE + 1 TRANSPARENT MODULES
(b = 1,50 m; h = 3,50 m) × 3; S_{tot} = 15,75 sqm

Code	Device	€/sqm	h	h/sqm
Scf	Scaffolding	**708,75**	**4**	**0,25**

2 OPAQUE + 1 TRANSPARENT MODULES (b = 1,50 m; h = 3,50 m) × 3; S_{tot} = 15,75 sqm	**Total cost (€)**	**€/sqm**	**h**	**h/sqm**
	18.716,25	**1.188,33**	**49**	**5,21**

OUTPUT

| 04



2 OPAQUE + 1 TRANSPARENT MODULES (b = 1,50 m; h = 3,50 m) × 3; S_{tot} = 15,75 sqm

Code	Elements	mm	€/sqm	sqm	Cost (€)	h	h/sqm
LStr1	1st Framing: Steel Profile UPN + hook joints + 4 steel brackets	300	801,22	15,75	12.619,25	3	0,19
LStr2	2nd Framing: Steel Tubolar Profile	115×115×6					
J1	Perimeter Connectors + Welded "U" Profiles for EPDM Gaskets	300×8	335,00	15,75	5.280,00		
LStr3	Panels ("Aquapanel")	12,5+12,5	150,00	15,75	2.362,50		
ExtIns	Stiferite	150	60,00	15,75	945,00		
ExtCl	Ext. Cladding: Brick Blocks + Cement Glue	120	290,00	10,50	3.045,00		
IntGap	Air Gap	10	75,00	10,50		6	0,38
Int(Fr)Ins	Steel Framing + Rockwool	50					
IntW1	Int. Counterwall: Fbr Plasterboard	12,5					
IntW2	Int. Counterwall: Plasterboard	12,5					
IntF1	Int. Finishing	0	10,50	10,50		3	0,19
WdS	Integr. Window System	385	220,00	5,25	1.155,00		
WdFC	False Ceiling		45,00	5,25	236,25		
WdThr	Threshold		25,00	5,25	131,25		
Wd	Window: Th. Cut All. Framing + Open. Panel + Double Glazing	75	1.550,00	5,25	8.137,50		
Bl	Blind	10	135,00	5,25	708,75		
IntF2	Int. Finishing		20,00	5,25	105,00		
		385	**2.204,79**		**34.725,50**	**12**	**0,76**
Total cost (€)					**34.725,50**		

OUTPUT

dello in esame, espressa dalla superficie di involucro/rivestimento);
   - la determinazione dei tempi di esecuzione, e della loro differenza, relativi al modello esecutivo tradizionale e al "prototipo cognitivo ottimizzato";
   - la determinazione sia del valore medio sia della riduzione dei costi indiretti di allestimento e gestione di cantiere, fino alla rilevazione del corrispondente costo unitario;
   - il calcolo della differenza di costo unitario tra il modello esecutivo tradizionale e il "prototipo cognitivo ottimizzato";
   - la configurazione preliminare dei trend di sviluppo degli output rispetto alla progressione della potenziale "quantità applicativa";
2. l'individuazione della "soglia di ottimizzazione", secondo l'allineamento economico tra il costo unitario del "prototipo cognitivo ottimizzato" e il costo unitario indiretto di gestione del cantiere, oltre la quale avviene la riduzione dei costi di capitale: ovvero, il "prototipo cognitivo ottimizzato" risulta vantaggioso a livello tecnico-economico e temporale (rispetto al modello esecutivo tradizionale), secondo i principi di *design-to-target value* (Fig. 5).

Osservazione dei risultati e proposte operative avanzate

Le pratiche eseguite dal *Technology Research & Development Office*, dirette alla gestione/riduzione della complessità dei sistemi costruttivi, confluiscono nell'espressione del "modello interattivo" e nell'individuazione della "soglia di ottimizzazione", intesi quale strumento e riferimento analitico orientati a:
1. la comprensione delle economie di scala per cui i processi di trasferimento incrementale e progressivo si dimostrano efficaci (rilevando, in forma sintetica e fattiva, la "quantità applicativa ottimale");
2. l'utilizzo circolare del "modello interattivo", agendo sugli indicatori e sui margini di *outcome* (ovvero, attraverso la trasformazione tecnologica degli input relativi alla variazione del valore medio e alla riduzione dei costi indiretti di cantiere) (Dewagoda *et al*., 2024; Prokhorova *et al*., 2024).

Gli esiti definiti dalla comprensione delle economie di scala e dalla possibilità di utilizzo circolare del "modello interattivo" costituiscono la base per l'approfondimento delle azioni progettuali, attraverso proposte metodologiche e operative avanzate, per il futuro e in modo originale, nel campo della Progettazione Tecnologica e Ambientale: questo prospettando sviluppi e dimensioni sia dell'ottimizzazione produttiva/costruttiva sia della sostenibilità verso gli *stakeholders* in esame. Le proposte avanzate riguardano il trasferimento calibrato di alcune prassi proprie della *Topology Optimization* e dell'*Advanced Manufacturing* nei confronti de:
1. gli *Architectural Engineering Services* (durante la fase di *processing prototype*) mediante la concezione di formule prestazionali specializzate dei sistemi costruttivi attraverso:
   - il trasferimento "endogeno", ovvero dagli ambiti di prefabbricazione avanzata delle interfacce strutturali e connettive dei sistemi meccanici (rispetto al funzionamento degli *unitized systems*, basati su tecniche di *framing/joint optimization*);

system, the divergent situation results from:
- the 85.54% increase in the unit construction cost of the "optimised cognitive prototype", compared to the traditional executive model;
- the 85.41% reduction of the unit construction time of the "optimised cognitive prototype" (considering the simultaneous building of almost all opaque and transparent modules), compared to the traditional executive model (Figs. 3, 4).

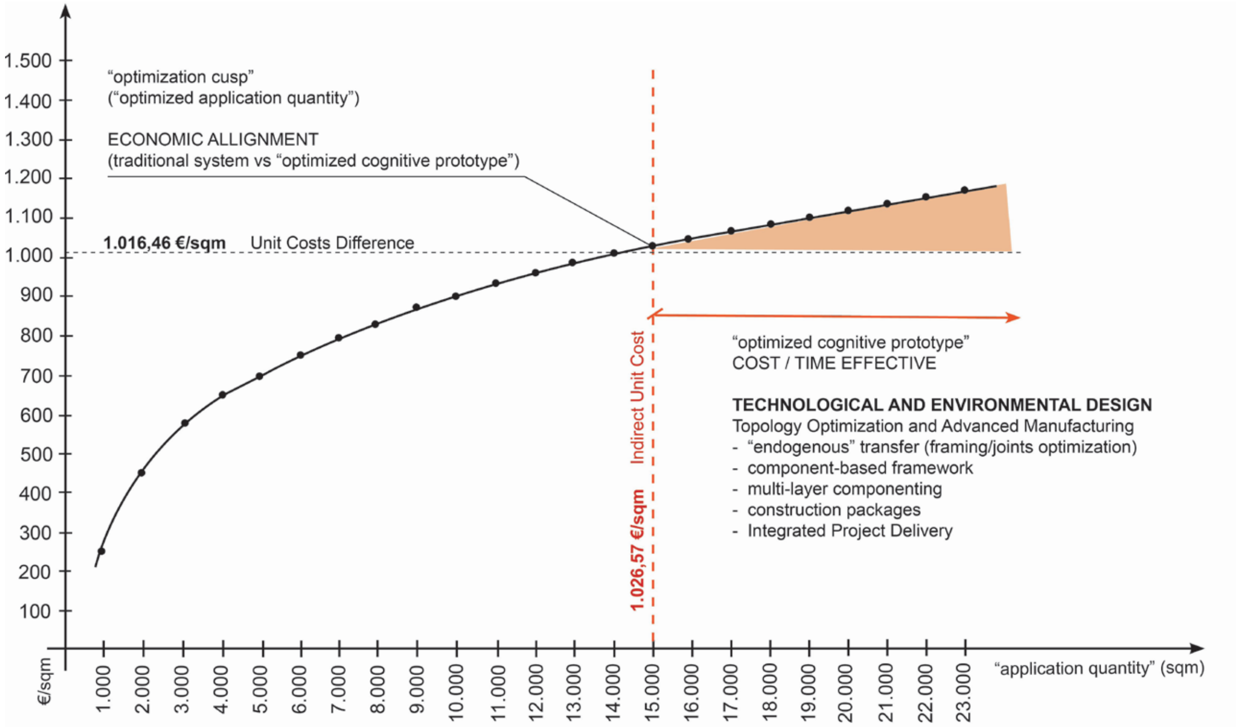
The thesis proceeds with an evaluation of the effectiveness of "technology substitution" and "type re-configuration" procedures (according to the inputs applied in the processing prototype phase, and the outputs from the evaluating prototype phase). The effectiveness of the examined practices, which can be quantified in terms of reducing capital costs (through the experimental study and the output deviation situation), is estimated through the original formulation of the "interactive (analytical-methodological) model", which allows:
1. the interpolation between parameters and evaluation metrics, through:
   - the use of the potential "application quantity" (in the examined model expressed by the envelope/cladding surface);
   - the determination of the construction times, and their difference, related to the traditional building system and the "optimised cognitive prototype";
   - the determination of both the average value and the reduction of indirect setting-up, keeping and management of on-site costs, up to recognition of the corresponding unit costs;
   - the computation of the unit cost difference between the traditional building system and the "optimised cognitive prototype";
   - the preliminary development trends of the output in terms of progression of the potential "application quantity";
2. the identification of the "optimisation cusp", according to the economic alignment between the unit cost of the "optimised cognitive prototype" and the indirect unit cost of site management, above which the reduction in capital costs is achieved: *i.e.* the "optimised cognitive prototype" becomes effective and economically/temporally advantageous compared to the traditional building system, according to the principles of design-to-target *value* (Fig. 5).

Observation of results and operative proposals

The practices carried out by the Technology Research & Development Office, aimed at controlling/reducing the complexity of building systems, lead to the expression of the "interactive model" and the recognition of the "optimisation cusp", understood as an analytical tool and reference, oriented towards:
1. explaining the economies of scale for which incremental and progressive transfer processes are effective (with reference to the "optimal application quantity" in a short and factual statement);
2. the circular use of the "interactive model", working on result indicators and ranges (*i.e.* through the technological transformation of inputs related to the change in the average value and the reduction of

05 | "Modello interattivo" e rilevazione della "soglia di ottimizzazione", Autore e Fabio Grossi (Smart Manufacturer, SMV Costruzioni)
"Interactive model" and drafting of "optimisation cusp", Author and Fabio Grossi (Smart Manufacturer, SMV Costruzioni s.r.l.)

| 05



"application quantity"	1.000		2.000		3.000		4.000		15.000	
Const. Time 1	5,21 h/mq	5.206,35 work h	5,21 h/mq	10.412,70 work h	5,21 h/mq	15.619,05 work h	5,21 h/mq	20.825,40 work h	5,21 h/mq	78.095,24 work h
Work Av. 1	162,70 work d	**7,07 months**	325,40 work d	**14,15 months**	488,10 work d	**21,22 months**	650,79 work d	**28,30 months**	2.440,48 work d	**106,11 months**
Const. Time 2	0,76 h/sqm	761,90 work h	0,76 h/sqm	1.523,81 work h	0,76 h/sqm	2.285,71 work h	0,76 h/sqm	3.047,62 work h	0,76 h/sqm	11.428,57 work h
Work Av. 2	23,81 work d	**1,04 months**	47,62 work d	**2,07 months**	71,43 work d	**3,11 months**	95,24 work d	**4,14 months**	357,14 work d	**15,53 months**
Const. Time Difference	**6,04 months**		**12,08 months**		**18,12 months**		**24,15 months**		**90,58 months**	
Av. Value Ind. Costs	**45.000,00**		**75.000,00**		**95.000,00**		**105.000,00**		**170.000,00**	
Saving Ind. Costs	**271.739,13**		**905.797,10**		**1.721.014,49**		**2.536.231,88**		**15.398.550,72**	
Ind. Unit Costs	**271,73**		**452,90**		**573,67**		**634,06**		**1.026,57**	
OUTPUT 1	1.188,33		1.188,33		1.188,33		1.188,33		1.188,33	
OUTPUT 2	2.204,79		2.204,79		2.204,79		2.204,79		2.204,79	
Unit Costs Difference	**1.016,46**		**1.016,46**		**1.016,46**		**1.016,46**		**1.016,46**	

"application quantity": potential envelope/cladding system surface (sqm)
Const. Time 1: Construction Time (traditional system)
Work. Av. 1: Work on Average (traditional system) of 3/4 operators/day (h work/ h 8 × 4)
Const. Time 2: Construction Time ("optimized cognitive prototype")
Work. Av. 2: Work on Average ("optimized cognitive prototype") of 3/4 operators/day (h work/ h 8 × 4)
Const. Time Difference: Construction Times Difference (between traditional system and "optimized cognitive prototype")
Ind. Costs Av. Value: Average Value Indirect Costs (€): setting-up, keeping and management site
Saving Ind. Costs: Saving Indirect Costs (€): setting-up, keeping and management site (45.000,00 € × ∆ months)
Ind. Unit Costs: Indirect Unit Cost (€/sqm)
OUTPUT 1: traditional system Unit Cost (€/sqm)
OUTPUT 2: "optimized cognitive prototype" Unit Cost (€/sqm)
Unit Costs Difference: Unit Costs Difference between "optimized cognitive prototype" and traditional system (€/sqm)
work h: work hours
work d: work days

– le tecniche di *component-based framework* (ovvero, attraverso la modulazione di apparati a intelaiature multiple o “continue”, spesso ottenute da *molding processes*) per l’integrazione di *pre-engineered* o *fabrication-ready components* (nel riferimento ai modi di *multi-functional parts design*) (Mesa *et al*., 2020) (Fig. 6);

2. i *Systems Manufacturing Stakeholders* (durante la fase di *evaluating prototype*) mediante la concezione di formule organizzative, gestionali e produttive di tipo *lean* (Arashpour, *et al*., 2017) attraverso:
   – le tecniche di *multi-layer componenting*, capaci di ridurre le emissioni di carbonio (pari al 25%, per superficie unitaria), conseguenti al trasporto (convogliando elementi tecnici, prodotti e materiali presso i *logistics hubs*, attrezzabili anche per le operazioni di assemblaggio *off-site*), i costi energetici, i consumi d’acqua e i tempi di costruzione *on-site* (pari al 30÷40% rispetto ai sistemi tradizionali) (LandSec, 2024);
   – la costituzione di filiere (nei modi di *co-working* per la composizione di *construction packages*), costituite da “piattaforme aperte” (quali *supply chain nodes*), operative in modalità continue e/o flessibili e adattabili (Fig. 7);
   – la partecipazione ad attività di *Integrated Project Delivery*, in connessione “di scopo” con i *Multi-Utility Services*, mediante la progettazione di sistemi costruttivi ottimizzati soprattutto per interventi di elevate dimensioni quantitative (Fig. 8).

indirect on-site costs; Dewagoda, *et al*., 2024; Prokhorova, *et al*., 2024).

The outcomes defined by understanding economies of scale and the possibility of the circular use of the “interactive model” are the basis to deepen project actions, through methodological and operative proposals, in an original way for the future, in the field of Technological and Environmental Design. This is achieved by exploring developments and dimensions of both production/construction optimisation and sustainability towards the *stakeholders* under examination. The proposals concern the calibrated transfer of some Topology Optimisation and Advanced Manufacturing practices to:

1. the Architectural Engineering Services (during the *processing prototype* phase) by developing specialised performance forms for building systems, through:
   – “endogenous” transfer, *i.e.* from the fields of advanced prefabrication of structural and connective interfaces of mechanical systems (referring to the functioning of unitised systems, achieved with “framing/joint optimisation” techniques);
   – *component-based framework* techniques (*i.e.* through the modulation of multiple or “continuous” framing devices, often obtained by molding processes) for the integration of pre-engineered or fabrication-ready components (referring to the multi-functional parts design modes; Mesa *et al*., 2020) (Fig. 6);
2. the Systems Manufacturing Stakeholders (during the evaluating prototype phase) by drafting lean organisation, management and production forms (Arashpour, *et al*., 2017) through:
   – the multi-layer component techniques, capable of reducing carbon emissions (by 25% per unit area), transport (by conducting technical elements, products and materials to logistics centres that can also be equipped for off-site assembly), energy costs, water consumption and on-site construction time (by 30÷40% compared to traditional systems; LandSec, 2024);
   – the constitution of networks (in the modes of *co-working* for the composition of construction packages), consisting of “open platforms” (such as supply chain nodes), operating in continuous and/or flexible and adaptable modes (Fig. 7);
   – the participation in Integrated Project Delivery activities, operating in a “scope” connection with Multi-Utility *Services*, through the design of optimised construction systems, especially for high volume works (Fig. 8).

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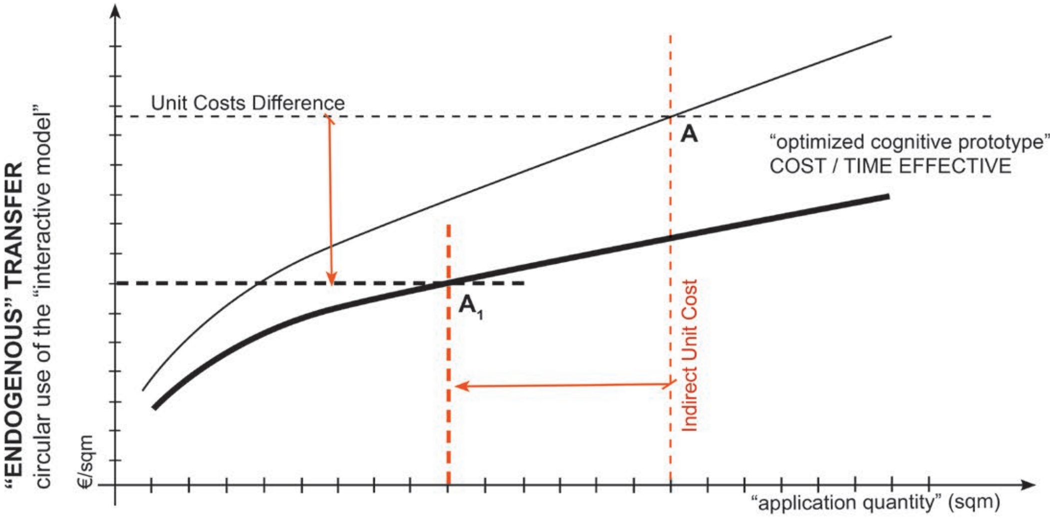
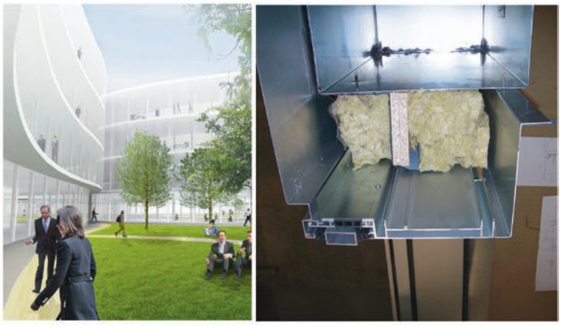


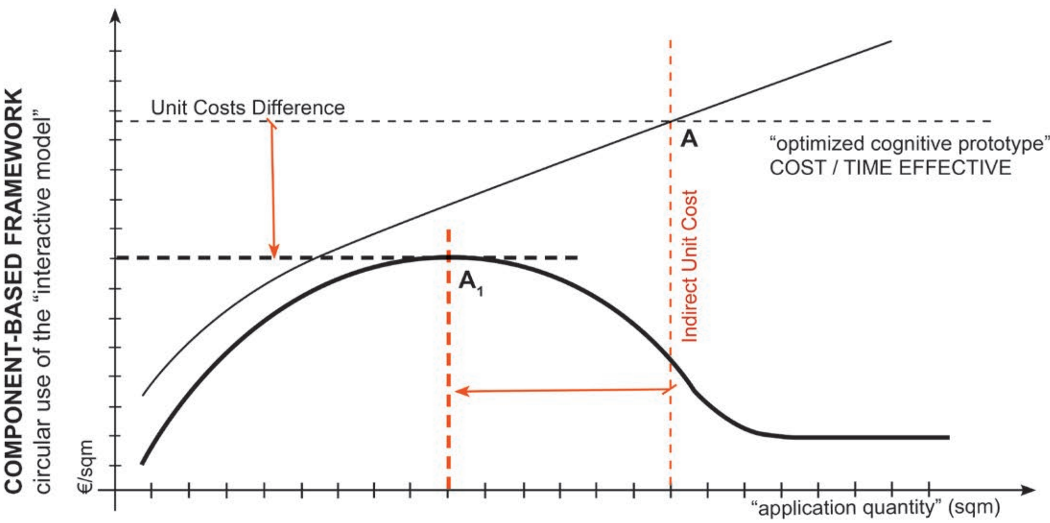
Critical rating
full-height envelope modules interposed to horizontal structures

"traditional system" (applicable)
construction on-site (*stick system* or *structural system*)

"optimized cognitive prototype"
framing/joint optimization techniques (processing of *hybrid unit system*)
- optimized topology: intrados/extrados application of adjustable substructures to the modules' upper/lower transoms

Technology transfer project
Massimiliano Nastri, Concept design, Architectural Engineering Services of SANAA, Campus of Commercial University "Luigi Bocconi", Milan





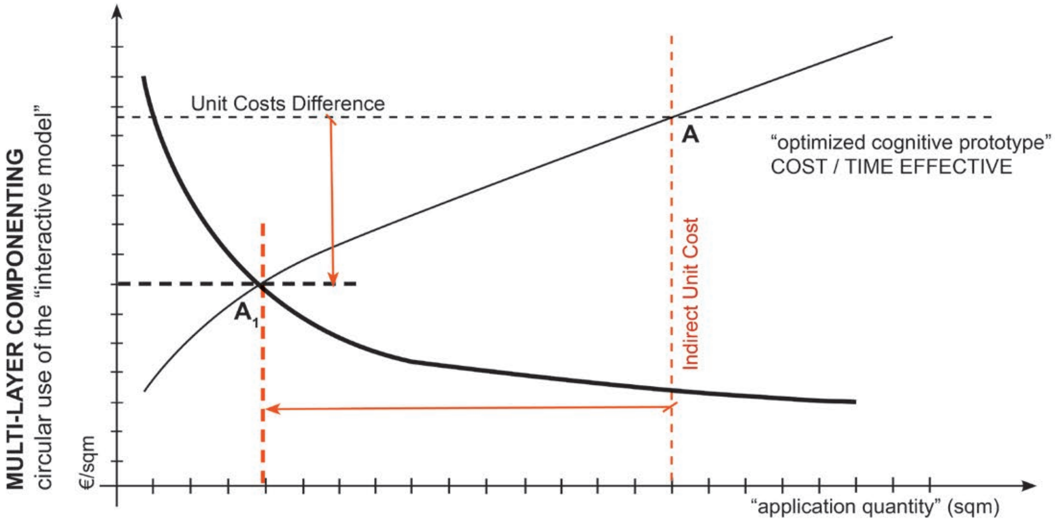
Critical rating
complexities of the extruded aluminium framing profiles

"traditional system"
construction on-site (*kit system*)

"optimized cognitive prototype"
multi-functional parts design (processing of façade/cladding system)
- optimized topology: "technological substitution" with prefabricated modules supporting porcelain stoneware panels

Technology transfer project
Material Balance Research, Department ABC, Politecnico di Milano, *Analysis and typology development for façade cladding systems*, Architectural Engineering Services of Granitifiandre S.p.A.

07 |

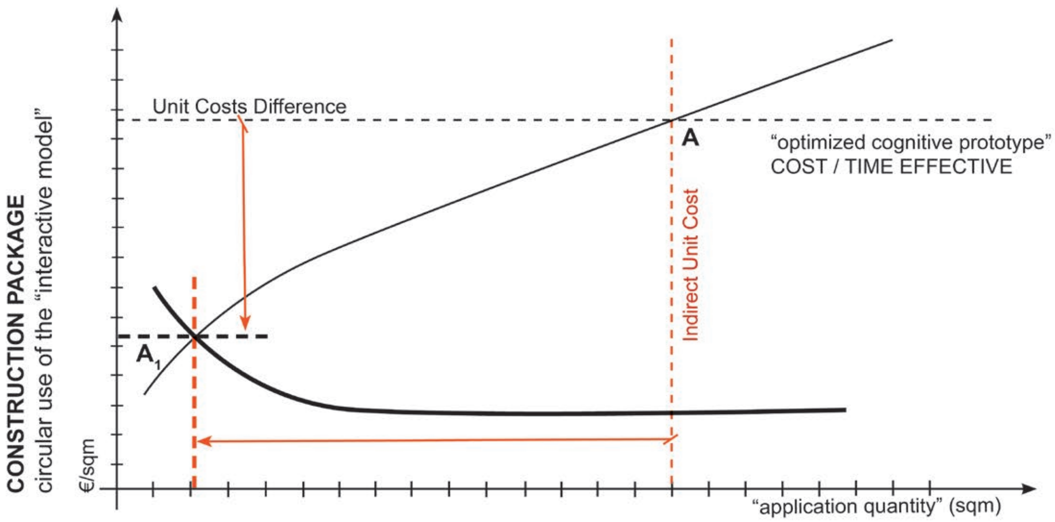


Critical rating
demand for adaptable and flexible envelope building system

"traditional system"
construction on-site (vertical massive load-bearing supports)

"optimized cognitive prototype"
multi-layer componenting (façade/cladding system)
- optimized topology: "technological substitution" with off-site pre-fabricated modules with custom-made framings

Technology transfer project
Stefan Trifonov (Schüco UK), Experimental prefabrication processing of multi-modular and mass-customized framed and layered system to support façade and massive cladding

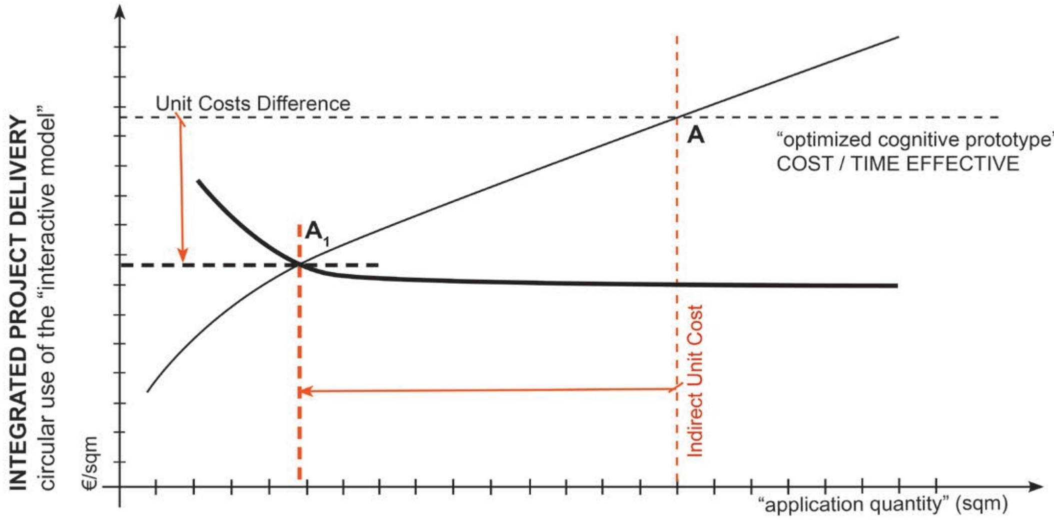


Critical rating
low cost/performing façade panelling suitable for asset types (domestic, education, health care and commercial buildings)

"traditional system"
construction on-site (vertical massive load-bearing supports)

"optimized cognitive prototype"
construction packages (constitution of "open platforms")
optimized topology: prefabricated "superblocks" made of gravel board, brick slips, reinforced concrete wind, mineral wool

Technology transfer project
Bryden Wood (UK), standardized/integrated logistics, planning and execution to form sub-assemblies

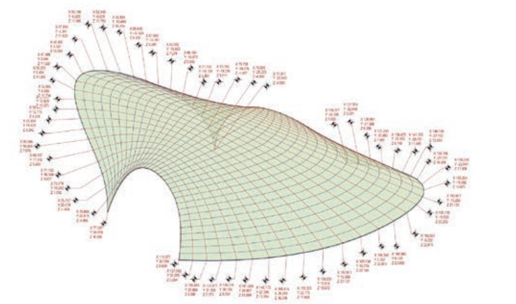


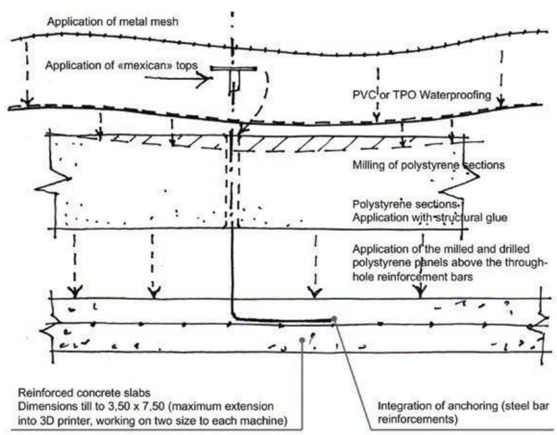
Critical rating
- replacement of the GRC cladding system for the main paraboloid extensions (for the percentage around 70%), foreseeing the use of GRC for the most tapered sections
- maintenance of morpho-typological and architectural objectives, aimed at showing the treatment of surfaces in the form of "cement" and "artefact dunes"

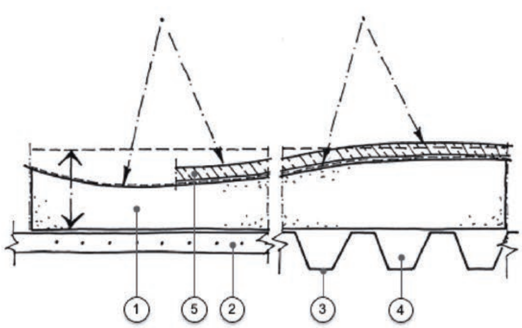
"traditional system"
multi-curve cladding technology based on the use of GRC, considered absolutely critical from the point of view of costs, production and site procedures

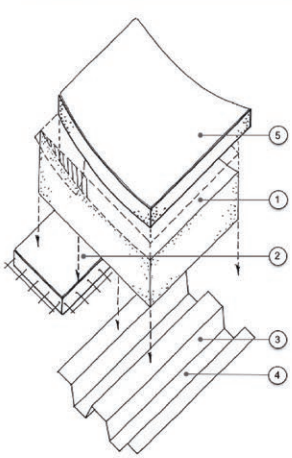
"optimized cognitive prototype"
optimized topology: "3D smart predalles" (concept design on the consolidated technology of the predalles, starting with the reinforced concrete slab and the polystyrene panel), through:
- 3D-milling of polystyrene sections, according to specific structural grid conditions (1)
- application of the milled polystyrene sections on reinforced concrete slabs (2) or on-site on corrugated sheets executed on the structural grid (3), with expanded clay or rockwool filling (4)
- application of "shotcrete" on the upper surface of the polystyrene sections, by 3D-printing (precast solution) or on-site (5)
- use/reduction of GRC coating in tapered curved sections
- cost and time reduction estimated at 30-35%
- reduction of specialized operators (assemblers, welders)
- use of site cranes and reduction of crane-trucks

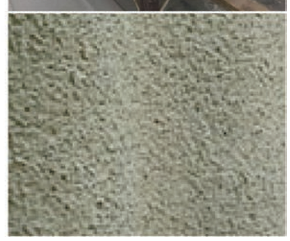
Technology transfer project
Material Balance Research, Department ABC, Politecnico di Milano, operating in "scope" connection with *Multi-Utility Services* (Rimond), Value engineering process of roof cladding systems, Norman Foster + Partners, *Red Sea International Airport* in Saudi Arabia, Partnership of Systems Manufacturing Stakeholders (Wasp, Edilmac)











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