AN APPROACH FOR EVALUATING EXTERNAL WALL-ROOF COUPLING DETAIL'S PERFORMANCE

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ABSTRACT

Designing a coupling detail is a complicated job since coupling details are areas where building elements and other sub-systems come together and performances of single building elements come into a complex interaction. Mistakes in the design stage can lead to building failures after construction, which on the other hand are causing unhealthy environments and high repair or retrofitting costs. The intersection areas in the external envelope, exposed to environmental conditions, are even more vulnerable to building failures. Building element systems of the external envelope do have several functions. Some of them are in common, but some functions are differing. These common and/or varying functions are coupled at the intersection area, working independently, cooperatively or opposing. This is why a complex interaction is born in a coupling detail. The coupling area of the exterior wall system with the roof system is one of those intersection areas of the external envelope. It is obvious that a way to avoid building failures is proper detailing.
In this paper, an approach to evaluate external wall-roof coupling detail's performance is presented. The evaluation approach consists of two modules. The first module is a "performance requirements checklist" separately generated for each building element, namely; the exterior wall systems and the roof systems. The second module is a step-by-step evaluation tool for coupling details. The tool and the checklists are prepared by taking into consideration of sole functional continuity at coupling details, supported by material continuity and geometric precautions. The evaluation tool can be used either in the detail design process or before the tendering process for finalized details.
The usability of the proposed approach is demonstrated through its application on a real world problem and pros and cons of the approach are discussed in conclusion.

Key words: Detail, Evaluation, Exterior Wall, Roof, Performance

1. INTRODUCTION

In some buildings failures occur a while after construction, affecting users' comfort and health and also causing high repair or retrofitting costs. The intersection areas in the external envelope, exposed to environmental conditions, are the most vulnerable

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parts of a building to failures. A remarkable reason for building failures are faulty designed details (Schild, 1984).
Intersection areas in the external envelope are coupling details where at least two building elements and/or other sub-systems such as the structural system come together (Rush, 1986). Each individual building element of the external envelope has to fulfill several functions. Some of them are in common, but some functions are differing. These common and/or varying functions are coupled at the intersection area, working independently, cooperatively or opposing (Emmitt, 2004). This is why a complex interaction is born in a coupling detail. The main goal has to be here the accurate integration of the systems and providing the continuity of performances at coupling details (Olie, 2011).Moreover, there is a great variety of building materials and a substantial amount of construction techniques, today. Due to this richness, it might be easier to prevent the building failures (Knaack, 2007). But at the same time, countless alternatives are causing a complex decision process. All those factors are leading to a complicated design process of the coupling detail which on the other hand also increases the risk of faulty design. Design errors should be detected at the design stage, to avoid carrying those mistakes to the construction stage. Although design review procedures at different scales to preclude those failures do exist, they rarely form a methodical approach for evaluating details.
In this paper, an approach to evaluate external wall-roof coupling detail's performance is presented. The evaluation tool can be used either in the detail design process or before the tendering process for finalized details. The proposed tool is to be used in the context of the building envelope, consisting of the exterior wall and roof systems.

2. METHODOLOGY

The evaluation approach consists of two modules. The first module is a "performance requirements check list" separately generated for each building element, namely; the exterior wall systems and the roof systems. The second module is a step-by-step evaluation tool for the exterior wall- roof coupling details.

2.1. Checklists for Performance Requirements for External Walls and Roofs

To propose a systematical approach in the context of building details, checklists were drawn up for building element systems as the first module of the analyzing approach. Checklists can be used as design or analysis tool in order to avoid overlooking any requirement which should be met by any product (Jones, 1992). These checklists were generated by determining all performance requirements for each building element through an extensive literature review. As the study is focusing on the intersection area of the exterior wall system and the roof system, firstly, performance requirements for exterior wall and roof systems were compiled in form of tables. Reliable resources, such as text books, guidelines and standards from years between 1970's and 2010's about building construction and details were used to identify performance requirements. Secondly, a frequency analysis was conducted to determine the most important requirements. Then, the performance

requirements were transformed into checklists for the exterior wall and the roof systems. Finally, checklists were tested on a great amount of typical building element details to control their accuracy and extensity. In this regard, a large number of roof and external wall details (Lückmann, 2011), (Beinhauer, 2013) were studied by using those checklists.

2.2. An Approach for the Evaluation of External Wall-Roof Coupling Detail's Performance

The second module of the proposed approach is a step-by-step evaluation tool for coupling details (Table 1).

Table 1: Flowchart of the support tool for analyzing coupling detail's performance

Step 1	Disassemble the coupling detail into building element details.
Step 2	Identify layers, materials, material properties and layer composition in building elements 1 and 2.
Step 3	Identify generic layer composition in building elements 1 and 2 separately.
Step 4	Identify functions which are fulfilled by each layer in building elements 1 and 2 separately.
Step 5	Determine if a functional layer has multiple functions for building elements 1 and 2 separately.
Step 6	Prepare a list for required performances for the intersection area "3".
Step 7	Check the continuity of functional layers from building elements 1 and 2 at intersection area 3. They can be either continuous, or discontinuous, or interrupted
Step 8	Check the continuity of functions at intersection area 3. They can be either continuous, or discontinuous, or interrupted.
Step 9	Check the geometric solutions by using the "geometric solutions table."
Step 10	Fill the intersection area evaluation table according to obtained data and evaluate the performances of intersection area if the number of precautions is enough and if they are correctly executed. Grading as +/o/-.

The evaluation tool is roughly developed by upgrading, adapting and reversing Emmitt's architectural detailing procedure which is a morphological method to develop new joint solutions (Emmitt, 2004). The evaluation tool comprises two aspects in analyzing the performance of coupling details. The first aspect is the layer composition of both building elements intersecting at the coupling detail and their continuity or discontinuity. The second aspect is the geometric characteristics leading to the form of the coupling detail. Layers of building elements and geometric solutions, both, might be used to fulfill the required performances. In the

performance analysis of coupling details, firstly, building element systems composing the coupling detail are disassembled and defined namely "1" and "2". Functional layers in the building element system sections are examined. Secondly, physical properties of building elements 1 and 2 are identified such as materials, layer composition and functional layers. Then functions for building elements 1 and 2 are defined and checked according to performance requirement tables as stated in section 2.1. The common performance requirements of the two building elements are considered to be the performance requirements of the coupling detail (Table 2). Then, physical properties of the intersection area are identified and it is controlled if the coupling detail is in continuity with building elements 1 and 2. After examining the material continuity, the continuity of functions is defined.

Table 2: An example for generating a table in terms of performance requirements related to water, water vapor and thermal performance for a coupling detail of the roof and the exterior wall

main performances	sub-performances	fulfilled performances by		
		roof	ext. wall	both roof & ext. wall
... RELATED TO WATER	impermeability to precipitation	X	X	X
	impermeability to splash water		X	
	impermeability to ground water		X	
	impermeability to domestic water (damage/ accident)		X	
	impermeability to wind-driven rain			X
	keeping water away in a controlled manner	X		
... RELATED TO WATER VAPOR	prevention of surface condensation	X	X	X
	prevention of interstitial condensation	X	X	X
	condensation control through ventilation	X		
THERMAL PERFORMANCE	low thermal conductivity	X	X	X
	heat storage	X	X	X
	durability against high temperatures	X	X	X
	durability against low temperatures	X	X	X
	avoid thermal bridges	X	X	X
	warmth to touch		X	
	prevention of heat gain	X		
	prevention of heat loss	X		

Geometric solution fulfilling performance requirements were also compiled by a literature review (Allen, 1993), (Knaack, 2007) and were expressed in form of a table. In the analysis of coupling details, geometric characteristics fulfilling performance requirements are defined and checked according to the "geometric solutions table" (Table 3). Finally, an evaluation table is generated in order to see all the design solutions that affect coupling detail's performance. Results of all steps in the evaluation module come in this table together and according to quantity and

quality of solutions, the required performances are graded through a three-level ordinal scale with scores assigned as; “good”(+), “moderate”(o) and “poor”(-). In this way, it is obtained which performance requirements are fulfilled by the coupling detail and how “successful” they are.

Table 3: “Geometric solutions” table (Allen, 1993), (Knaack, 2007)

performance	geometric solutions
…related to water	wash
	overlap
	overhang and drip
	drain and weep
	capillary break
	labyrinth
	rainscreen
	upstand

performance	geometric solutions
…related to water vapour	condensate drainage

3. THE USABILITY OF THE PROPOSED APPROACH IN ANALYZING EXTERIOR WALL-ROOF COUPLING DETAILS

Two coupling details are analyzed with the evaluation tool in order to demonstrate its usability. Thermal performance, performance related to water and water vapor of the coupling details are taken into consideration.

3.1.Aflat roof-exterior wall coupling detail

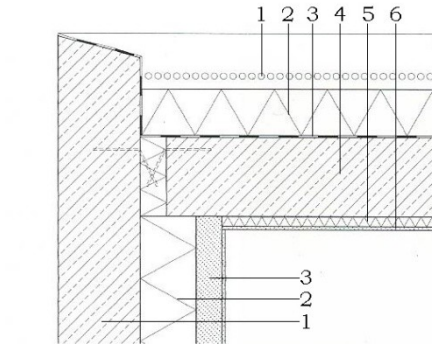


*Figure*1: Ext. wall-flat roof coupling detail, “House in Zurich, Switzerland” (Detail, 2008, 1/2, p. 35.)

Step 1: Disassemble the coupling detail into typical building element details.(Fig.1)
building element 1: roof system

building element 2: exterior wall system

Step 2& 3: Identify layers, materials, material properties and layer composition in building elements 1 and 2. (Table 4, 5)
Identify generic layer composition in building elements 1 and 2 separately.

Table 4: building element 1; roof system

no	materials	generic layer
1	gravel, 50 mm	ext. finishing layer
2	XPS, 140 mm	thermal insulation l.
3	liquid-plastic sealant	waterproofing layer
4	R.C., 240 mm	core
5	mineral based acoustic board, 30 mm	acoustic board
6	mineral based coat, 10 mm	internal finishing layer

*Table*5: building element 2; exterior wall system

no	materials	generic la.
1	concrete, 250 mm, mortar (with gravel and black pigments)	core
2	foamed glass, 160 mm	thermal insulation l.
3	plasterboard, 80 mm + plaster, 3 mm	internal finishing l.

Step 4: Identify functions which are fulfilled by each layer in building elements 1 and 2 separately. (Table 6, 7)

Table 6: building element 1; roof system, layer-function table

Generic layer	Function
ext. finishing l.	+ preventing heat gain
thermal insulation layer	low thermal conductivity
waterproofing l.	water impermeability + vapor barrier
core	
acoustic board	
int. finishing l.	

*Table*7: building element 2; exterior wall system, layer-function table

Generic layer	Function
core	+water impermeability + heat storage
ther. insulation layer	low thermal conductivity
int. finishing l.	

Step 5: Determine if a functional layer has multiple functions for building elements 1 and 2 separately.

b.e. 1: roof system
1 External finishing layer
3 Waterproofing layer

b.e. 2: exterior wall system
1 Core

Step 6: Prepare a list for required performances for the intersection area "3".

<u>Performance related to water:</u>
Water impermeability
Impermeability to wind-driven rain

<u>Thermal performance:</u>
Low thermal conductivity
Heat storage

Avoid thermal bridges (required only from the coupling detail)
Preventing heat gain

Performance related to water vapor:
Prevention of interstitial cond.
Prevention of surface condensation

Step 7: Check the continuity of functional layers from building elements 1 and 2 at intersection area 3.They can be either continuous, or discontinuous, or interrupted. (Table 8)

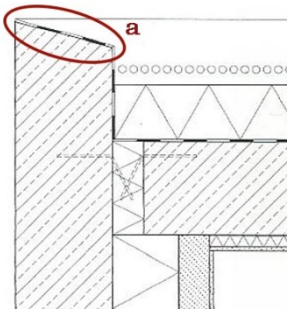
Table 8: Functional layer continuity table

1, roof system	**2, exterior wall system**	**3, intersection area**
External finishing layer		- discontinuous
Thermal insulation layer	Thermal insulation layer	✓ continuous
Waterproofing layer		- discontinuous
Core	Core	× interrupted
Acoustic board		- discontinuous
Internal finishing layer	Internal finishing layer	✓ continuous

Step 8: Check the continuity of functions at intersection area 3.
They can be either continuous, or discontinuous, or interrupted. (Table 9)

Table 9: Performance continuity table

1, roof system	**2, exterior wall system**	**3, intersection area**
Perf. related to water	Perf. related to water	✓ continuous
Thermal performance	Thermal performance	✓ continuous
Performancerel. to water vapor	Performance rel. to water vapor	-



Step 9: Check the geometric solutions by using "geometric solutions table." (Tab. 2)
("✓" is used as "existing"; "×" is used as "non-existing".)

aWash ✓
bOverlap ×
cOverhang and drip ×
dDrain and weep ×
eCapillary break ×
fLabyrinth ×
gRainscreen×
hUpstand×

*Figure*2: geometric solutions in coupling detail

Step 10: Fill the intersection area evaluation table according to obtained data and evaluate the performances of the intersection area if the number of precautions are enough and if they are correctly executed. Grading should be as +/o/-. (Table 10)

Table 10: intersection area evaluation table

Performance	**Geometric solutions**	**Insulation & sealing layers**	**Performance continuity**	**Functional layer continuity**	**Evaluation**
Performance related to water	wash	waterproofing layer (liquid)	(+)	(o)	(o)
Ther.performance	-	ther.insulation	(+)	(+)	(+)
Perf. related to water vapor	-	-	(-)	(-)	(-)

According to the evaluation, the thermal performance and performance related to water of the coupling detail can be classified as acceptable, whereas the performance related to water vapor is at an insufficient level. Some revisions of the detail are needed to upgrade it to obtain an acceptable overall performance.

3.2. A pitched roof-exterior wall coupling detail

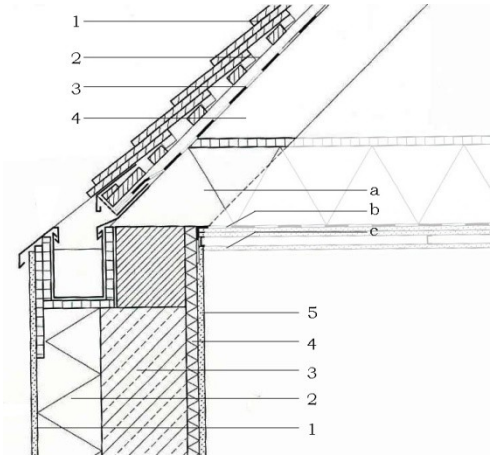


Figure 3: Analyzed exterior wall-roof coupling detail "Parish Hall, Hailfingen, Germany" (Detail, 2011, 10, p.1188)

Step 1: Disassemble the coupling detail into typical building element details. (Fig. 3)

building element 1: roof system
building element 2: exterior wall system

Step 2 & 3: Identify layers, materials, material properties and layer composition in building elements 1 and 2. (Table 11, 12)
Identify generic layer composition in building elements 1 and 2 separately.

Table 11: b. e. 1; roof system

no	materials	generic layer
1	natural tiling, 180/380 mm	external finishing layer
2	battens, 50/40 mm + rear ventilated layer	complimentary components + air gap
3	moisture-diffusing membrane	waterproofing layer
4	rafters, 100/180 mm	core

Table 12: b. e. 2; exterior wall system

no	materials	generic layer
1	fabric-reinforced rendering, 16 mm	external finishing layer
2	mineral wool insulation, 160 mm	ther. insulation layer (1)
3	reinforced concrete wall, 250 mm	core
4	XPS, 20 mm	ther. insul. l. (2)
5	plaster, 15 mm	int. finishing l.

Step 4: Identify functions which are fulfilled by each layer in building elements 1 and 2 separately. (Table 13, 14)

Albeit the coupling detail is considered to be consisted of two building element systems, components from the ceiling construction (in Fig. 11 a, b, c) which intersect with this detail and share the volume of the roof system also has to be taken into consideration to conduct an accurate performance analysis. e.g., partial thermal insulation from the ceiling construction adjacent to the intersection area is counted as a part of the roof system.

Table 13: building element 1, roof system, layer-function table

Generic layer	Function
1 External finishing layer	+ water impermeability
2 Rear ventilated layer	condensation control through ventilation
3 Waterproofing layer	water impermeability + condensation control through ventilation
4 Core	
athermal insulation	preventing heat gain/loss

Table 14: building element 2, exterior wall system, layer-function table

Generic layer	Function
1 External finishing layer	+ water impermeability

2 Ther.insulation layer (1)	preventing heat gain/loss
3 Core	+ heat storage
4 Thermal insulation layer (2)	preventing heat gain/loss + avoid thermal bridges + preventing surface condensation
5 Internal finishing layer	

Step 5: Determine if a functional layer has multiple functions for building elements 1 and 2 separately.

b. e. 1: roof system
1 External finishing layer
3 Waterproofing layer

b. e. 2: exterior wall system
1 External finishing layer
3 Core
4 Thermal insulation layer (2)

Step 6: Prepare a list for required performances for the intersection area "3".

Performance related to water:
Impermeability to precipitation
Impermeabilityto wind-driven rain

Thermal performance:
Low thermal conductivity
Heat storage
Avoid thermal bridges

Performance related to water vapor:
Prevention of interstitial cond.
Prevention of surface condensation

Step 7: Check the continuity of functional layers from building elements 1 and 2 at intersection area 3.They can be either continuous, or discontinuous, or interrupted. (Table 15)

Table 15: Functional layer continuity table

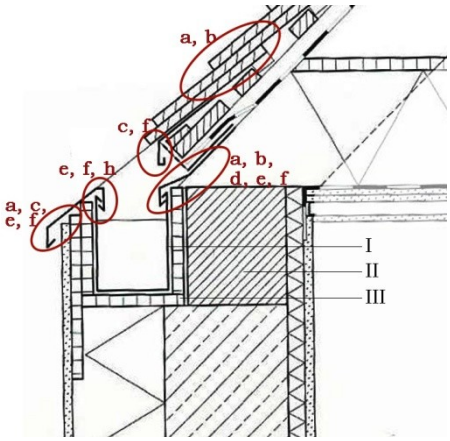
1, roof system	**2, exterior wall sys.**	**3 intersection area**
1 External finishing layer	1 Ext. finishing layer	× interrupted
2 Rear ventilated layer		- discontinuous
3 Waterproofing layer		- discontinuous
4 Core	3 Core	✓ continuous
a- Thermal insulation layer (from the ceiling construction)	2, 4 Ther. insulation layer (1&2)	✓ continuous
b- Vapor-retarding layer (from the ceiling construction)		- discontinuous
c- Internal finishing layer (from the ceiling construction)	5 Internal finishing layer	✓ continuous

Step 8: Check the continuity of functions at intersection area 3.
They can be either continuous, or discontinuous, or interrupted. (Table 16)

Table 16: Performance continuity table

1, roof system	**2, exterior wall system**	**3, intersection area**
Performance rel. to water	Performance rel. to water	✓ continuous
Thermal performance	Thermal performance	✓ continuous
Perf. rel. to water vapor	Perf. rel. to water vapor	- discontinuous

Step 9: Check the geometric solutions by using "geometric solutions table."(Tab. 2) ("✓" is used as "existing"; "✗" is used as "non-existing".)



a Wash ✓
b Overlap ✓
c Overhang and drip ✓
d Drain and weep ✓
e Capillary break ✓
f Labyrinth ✓
g Rainscreen ✗
h Upstand

Figure 4: geometric solutions in coupling detail

Step 10: Fill the intersection area evaluation table according to obtained data and evaluate the performances of the intersection area if the number of precautions is enough and if they are correctly executed. Grading should be as: +/o/-. (Table17)

Table 17: intersection area evaluation table

Perf.	**Geometric solutions**	**Insulation & sealing layers**	**Compl. components**	**Perf. cont.**	**Func. layer cont.**	**Eval.**
Perf. related to water	Overhang and drip		Sheet zinc gutter -I	(+)	(-)	(+)
	Wash					
	Overlap					
	Drain and weep					
	Capillary break					
	Labyrinth					
Thermal perf.	-	Thermal insulation layers	wood purlin -II + plywood gutter boards -III	(+)	(+)	(+)
Perf. related to water vapor	-	Vapor retarder + Thermal insulation layer (2)		(o)	(-)	(o)

According to the evaluation, thermal performance, performance related to water and performance related to water vapor of the coupling detail can be classified as acceptable. As the performance related to water vapor is slightly lower than other performances, upgrading should be considered.

4. DISCUSSION AND CONCLUSION

An approach to evaluate external wall-roof coupling detail's performance is presented. The evaluation approach consists of two modules. The first module is a "performance requirements check list" separately generated for each building element, namely; the external wall systems and the roof systems. The second module is a step-by-step evaluation tool for coupling details. The usability of the proposed approach is demonstrated through its application on two real world

problems. The evaluation approach is to be used in the design process as a design review tool to avoid building failures caused by faulty design.

Futures of the evaluation tool are as follows:

- The tool is established upon investigating existing details, so it is also a means to analyze how an architect works on a detail and what he/she thinks while designing. In other words, the proposed tool reveals the "nature" of design and helps to understand how a detail is "born".
- The tool provides an explicitly organized, rationalized method that complicated detailing process becomes clear for the architect at design stage.
- The tool does not only evaluate a coupling detail of two building elements, it also evaluates the typical building element details.
- It shows that fulfillment of performances at intersection area depends on the performances existing in typical building element details and their continuity at intersection areas.
- If a coupling detail is regarded as not sufficient according to the evaluation, hints can be found in the evaluation table, for feed-back and redesigning the detail.
- Since the module is based on ranking and scaling methods, self-evaluation is easy for designers.

Still, there are some flaws or some points to fulfill:

- In the grading step of the evaluation tool, a certain level of expertise on related areas is required.
- The analyzing module, if necessary, should be quantitative for more precise evaluation.
- The evaluation tool should also be extended to cover all types of building elements and sub-systems and their combinations in creating coupling details.

The development of the tool continues with respect to the findings from the applications.

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