Building Enclosures using SEED-Config

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We describe enclosure design for SEED-Config using an example from "Architectural Details for Insulated Buildings" [Brand 90]. We develop enclosures for insulated buildings in terms of the functional units that specify them, the technologies that implement them and the design units that describe them. Brand gives details in eight series (A-H); in each series he describes a specific detailing system. We base our exposition on series A to E: these share the property of the wall fitting partially under the roof and floor slabs. In series F and G the wall stands clear of the slabs and this would require a different approach to detailing from a very high level. Series H is a compendium of special cases that we do not discuss here at all. We conclude with a discussion of what our enclosure design example implies for the representation and computational engine of SEED-Config. We chose insulated enclosures as our example for a specific reason: Brand's treatment of them is proximate to the fundamental approach we take in SEED. Brand wrote in clear, rulelike terms that progress from the abstract to the specific. He explicitly links each part of every detail to the function it fulfils.

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1 Enclosure design

The postwar period in several countries saw a great expansion of building science. In countries with cold climates the researchers involved faced a particularly ugly and costly problem. It had become common to both tightly control indoor thermal environments and to insulate building enclosures. Together, these created new modes of building degradation and failure, typically involving some combination of air leakage, ice lensing, thermal bridging and vapour diffusion. Subject to these phenomena, building envelopes failed, often dramatically and very expensively. During the 1960's to 1980's researchers created a new applied science aimed at understanding and designing building enclosures for these severe climates. They aimed to understand the function of enclosures, the physical phenomena at play in them, and how such phenomena affected an enclosure over its lifetime. They also aimed to develop stable enclosures, i.e., enclosures that would function, without significant degradation, for long periods. A cold climate is a strong imposition on building research: a successful response demands good science. In Canada that science grew at the Division of Building Research (DBR) at the National Research Council and was reported, not only in scholarly articles, but in a series of publications called the Canadian Building Digests [CdnBldgDig]. In 1973, J.K.Latta at the DBR published a book entitled "Walls, Windows and Roofs for the Canadian Climate" [Latta 73] which summarized both the physical phenomena at play and the abstract design response archetypally known as the rainscreen wall. In 1990, R. C. Brand of Carleton University [1] published "Architectural Details for Insulated Buildings" [Brand 90] which made the earlier work concrete: in eight series of details he showed how durable insulated enclosures could be designed and constructed.

Our knowledge of insulated enclosures is thus of a special kind. It relates the function of the enclosure to the physical phenomena which act on the enclosure and to the design of enclosures. This makes insulated enclosures an ideal case study for developing an automatic design system such as SEED.

Brand [Brand 90, pp5-6] describes an insulated enclosure by instructing the designer to:

(1) Enclose the building in a continuous air-barrier.

(2) Provide continuous support for the air-barrier against wind loads.

(3) Ensure that the air-barrier is flexible at joints where movement may occur.

(4) Provide continuous insulation to keep the air barrier warm and to conserve energy in the building.

(5) Keep the insulation tight to the air barrier.

(6) Protect the insulation with a rainscreen/sunscreen supported out from the structure in a way that does not penetrate the insulation with excessive heat bridges.

(7) Provide enough open space for drainage and construction clearances between the rainscreen and the insulation.

(8) Drain the wall cavity to the outside.

He gives abstract drawings of such enclosures and develops these in eight specific technologies. Brand contends that his abstract description comprising four layers (continuous support, air barrier, insulation and rain/sunscreen) applies to most insulated buildings-but he does presume construction systems most commonly found in large scale buildings. The distinguishing feature of such systems are that the structure is largely independent of the enclosure that surrounds it; indeed Brand would contend that vertical structure should not be spatially coincident with the enclosure.

The wall system dominates Brand's description as it introduces the greatest complexities of detailing. In a wall there are two archetypal connections between enclosure and structure: between a wall and the bottom of a slab and between a wall and the top of a slab. Figure 1 shows the wall/slab-bottom intersection which presumes a gap between the top of the continuous support layer of the wall and the bottom of the slab to allow for structural deflection and other movement. Figure 1 also shows the wall/slab-top intersection in which the continuous support layer of the wall actually rests on the slab. In both cases, what is actually relating to the slab is not the entire wall but only the continuous support layer. The rest of the wall is constructed outside of this component. This part of the wall is what holds the rest of the wall assembly in place: it simply provides structural support for other components.

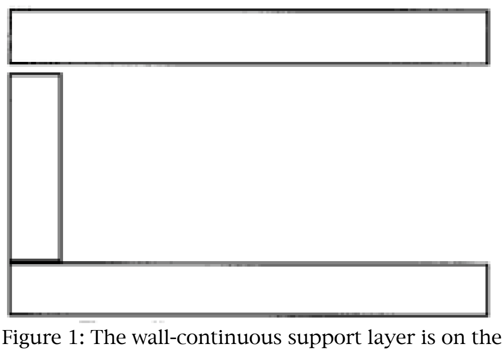

Figure 1: The wall-continuous support layer is on the top of roof-continuous support layer and rests on the floor slab

A continuous air-barrier lies over the continuous support layer. In concept the air barrier is simple: it is directly attached to the continuous support layer. In practice complications arise at both the gap between the continuous support layer and the bottom of the slab, and the transition from a vertical to horizontal orientation of the air barrier. The air-barrier is the actual "wall"-it divides the "inside" of the building, from the "outside"; it "stops the weather"; and it prevents most mechanisms of building detioration. The other elements of the enclosure mostly provide support functions to the air barrier.

Insulated-enclosure is-a technology

Precedent:
- there must exist a functional unit for a building enclosure
- this functional unit must not be allocated or elaborated

Consequent:
- allocate the building enclosure functional unit as an insulated enclosure
- elaborate the building enclosure functional unit with constituents for the sub-enclosure and for the joints per the first level of the functional unit hierarchy

Figure 2: An example of a technology, showing precedent and consequent parts.

A continuous insulation layer over the airbarrier has two functions. First, it keeps the air-barrier warm, thus preventing condensation on the inside of the air barrier. Second, it reduces energy flow through the building envelope, thus allowing greater control of the internal thermal environment. For both functions the insulation layer must be in direct contact with the air-barrier, for example, the oft-used method of attachment with daubs of glue results in an unacceptable gap.

A rain/sunscreen layer protects the insulation from rain, sun, wind, and other forces. On walls, it prevents water from reaching the insulation layer. On roofs the insulation is waterproof, so the rain/sunscreen layer acts primarily as a sunscreen and ballast.

Joints between walls and roofs are difficult as the type and function of the material layers change from the wall to the roof. The archetypal response is a sort of cap (Brand calls it an "umbrella") over the joint that protects the top of the wall assembly from sun and rain. The cap is realized physically as a parapet that creates a shallow dish of the roof. This dish functions to retain the insulation and its ballast on the roof and to prevent roof rainwater from flowing over the sides of the building.

1.1 SEED-Config basics

Within SEED, the term configuration design refers to the design of a three dimensional building model in terms of spaces, subsystems and actual physical components. In principle, configuration design includes all the three-dimensional aspects of building design -decisions about the overall form of the building, structure, enclosure, mechanica, electrical and conveyance systems are all part of configuration design. Clearly, configuration design practice and content varies widely across firms, building component manufacturers design in which building are built. Just as clearly, within a single building project, several different firms may engage in aspects of configuration design. Effective computer support for configuration design must provide for this multiplicity of apparently specialize c[needs.

SEED-Config is the module within SEED that supports configuration design. It provides four kinds of support to this end. First, its representation is based on elements that represent buildings as highly interrelated collections of objects, which carry both functional and formal descriptions. Second, it is a general device for rapidly generating and evaluating, alternative designs. In this role it acts by using devices called technologies to generate sign representations in response to a design problem. Third, it supports storage and retrieval of chosen design problems and solutions as cases, in which role it uses a general database as a repository of stored design work. Fourth, it is an extensible device with which new technologies can be developed and old ones modified. With these four features, we may compare SEED-Config to conventional CAD systems. In the conventional world, there are many systems that provide drafting support-the elements they place are geometric objects, text labels, dimensions, etc. and collections of these. The more sophisticated of these systems, for example, AutoCAD [AutoCAD 93], have programmable computing languages within them. These languages are used to extend (most often specialize) the capabilities of the system for a specific task. Conventional systems focus on drawing description-SEED-Config on creation of design alternatives. Conventional systems rely entirely on the designer to develop designs-the technologies of SEED-Config can play a more actively role in developing designs. Conventional systems treat each drawing (or drawing collection) as an independent object-SEED-Config treats each generated design as a potential design case. Conventional systems are extended by adding new commands and modifying existing ones-SEED-Config is extended by creating an modifying technologies.

SEED-Config shares with the rest of SEED a common conceptualization of design tasks; a common basic user interface design; and the ability to accept as input representations created by other modules. It differs in that its representation uses three dimensional data, specifically a non-manifold solid model, elements of which may be parametric, that is, they may be constrained to a range of spatial positions rather than occupying a specific position at a particular point in time.

In this paper, we show technologies for automatic enclosure design using the terms and mechanisms of the developing SEED-Config system.

1.2 *Knowledge level concepts*

Five of SEED's main concepts organize the basic action of SEED-Config in generating designs: (1) functional units, (2) design units, (3) technologies, (4) states, and (5) design spaces. In brief, design spaces comprise states which are linked to each other by the operations required to derive one state from another. States comprise a problem, represented as functional units (FU's) and a solution to that problem, represented as design units (DU's): DU's and FU's exist in one-to-one correspondence. SEED-Config acts to generate designs by creating and elaborating states comprising FU's and DU's to explore design spaces. For the further information of SEED-Config, please consult our Web sites (SEED in general, http://seed.edrc.cmu.edu/, or directly SEED-Config at Adelaide, http://www-seed.arch.adelaide.edu.au/).

2 Technologies for enclosure design

At the outset we have a building massing and the knowledge that we intend an insulated enclosure around it. Technologies contain the information necessary to develop a specific insulated enclosure.

The technologies descend an abstraction hierarchy. First the essential enclosure types, then the actual geometric regions, then the functional layers of each enclosure subsystem, then the geometry of each of the functional layers (joints last!). Every technology has one precedent, and one consequent which will do the matching (precedent) and the action (consequent). One example of the informal representation is as follows

The technologies can be applied in a sequence to create a specific enclosure-one such sequence is described in the series Figure 3 to Figure 14. The sequence can further be decomposed into five phases as follows:

(a) creation of a functional unit hierarchy for all specific functional enclosure types.

(b) geometric subdivision of the building massing into regions for each enclosure type.

(c) elaboration of each enclosure region into functional layers.

(d) independent allocation of each non-joint enclosure type, layer by layer.

(e) allocation of the joint enclosures, layer by layer. These modify the layers of the enclosure surfaces that they join.

2.1 *Functional enclosure types*

The first level functional unit hierarchy is shown in Figure 3.

2.2 *Geometric subdivision of the building massing boundary*

The abstract building (firestation) [Zurier 82] and some of its different enclosure regions are shown in Figure 4.

2.3 *Elaboration of each enclosure region*

Elaborate each region (roof, wall, and joint design units in this paper), into a different functional unit hierarchy, shown in Figure 5 and Figure 6. Each new constituent in the hierarchy will correspond to a physical layer in the enclosure design. The wall and roof have functionally identical layer structures. The joint between them is slightly more complex and will, when physically realized, "stitch" the two regions together.

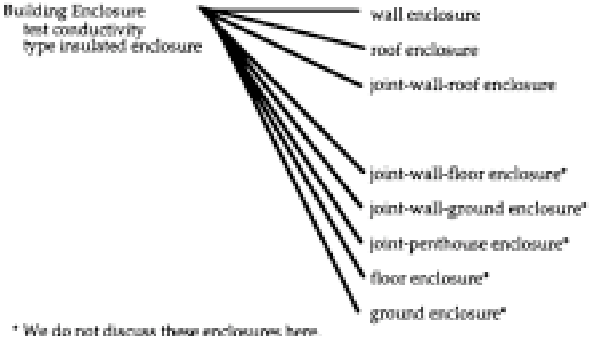

Figure 3: The first level functional unit hierarchy for the insulation enclosure

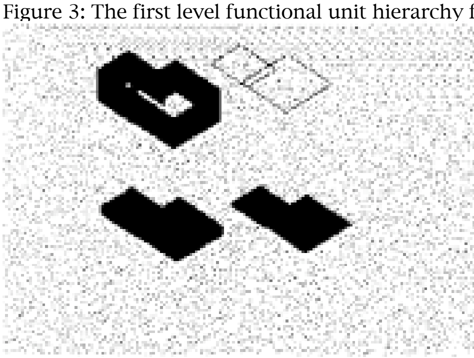

Figure 4: Abstract enclosure elements, being, anti-clockwise from the top left, a wall enclosure, a ground enclosure a roof enclosure and an enclosure for the joint between the wall and roof.

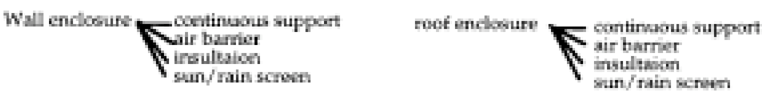

Figure 5: Wall enclosure (left) and roof enclosure (right) functional hierarchy

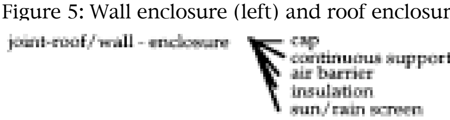

Figure 6: Joint-wall-roof enclosure functional unit hierarchy

2.4 *Allocation of the enclosure surface components*

Technologies similar to each other develop physical layers allocating each functional layer of each region in the enclosure. As shown in Figure 7 and Figure 8, these technologies work independently of their context. It remains to the joint technologies to reintegrate the layers into a workable building enclosure design.

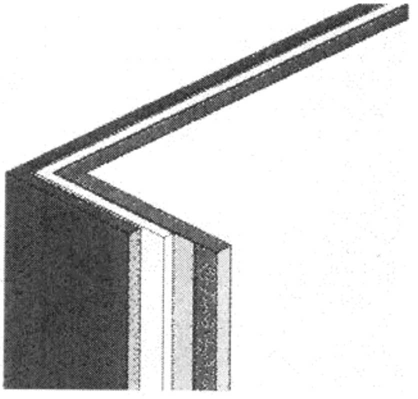

Figure 7: The sun/rainscreen, insulation, air barrier, and continuous support design units (from outside to inside) of wall enclosure. Wall enclosure, like roofs, are allocated independently of those for adjoining enclosure elements.

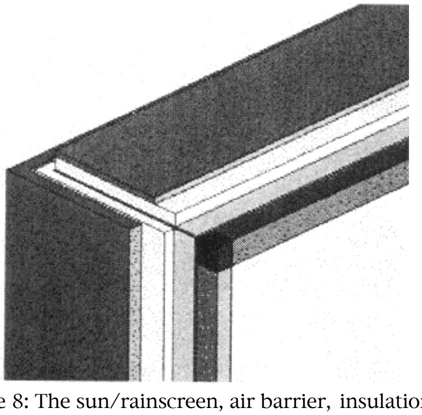

Figure 8: The sun/rainscreen, air barrier, insulation, air barrier, continuous support (membranes) design units of roof and wall enclosure (before the joint technology). Note that the wall and roof continuous support layers overlap at this stage.

2.5 Allocation of the enclosure joint components

Technologies allocating joint enclosures (the joint between the roof and wall enclosures here) modify the enclosures they join layer by layer. In addition, the roof /wall joint enclosure has its own special layer: the cap, which is shown in Figure 9. The cap is placed first, as each of the subsequent layers respond to its geometry. The continuous support layer technology (Figure 10) lowers the top surface of the wall continuous support layer and places a metal strip that acts as continuous support across the resulting gap. The air-barrier layer technology (Figure 11) ensures that there is a continuous air-barrier in the region of the joint. There is much variability in the way this layer can be allocated. The insulation layer technology (Figure 12) adjusts the insulation layers of the adjoining enclosures and adds insulation within the cap assembly. The rain/sunscreen layer technology (Figure 13 and Figure 14) completes the membrane and flashing on the cap as well as modifying the adjoining enclosure layer. This completes the enclosure design at the joint.

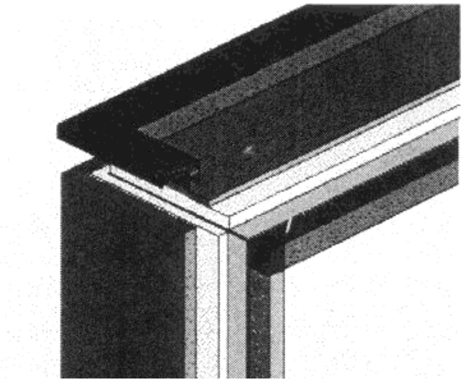

Figure 9: The cap design unit is placed on top of the roof continuous support layer. When placed, it spatially overlaps the air-barrier, insulation and sun/rainscreen layers of the roof. These intersections are resolved by the technologies for each of these layers within the joint.

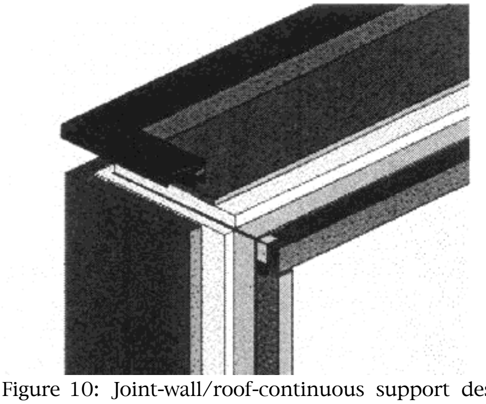

Figure 10: Joint-wall/roof-continuous support design unit (shown with all other layers). Note that there are two segments of continuous support provided at the joint. One is simply a portion of the roof slab surface; the other is a steel plate attached to the outside face of the roof slab.

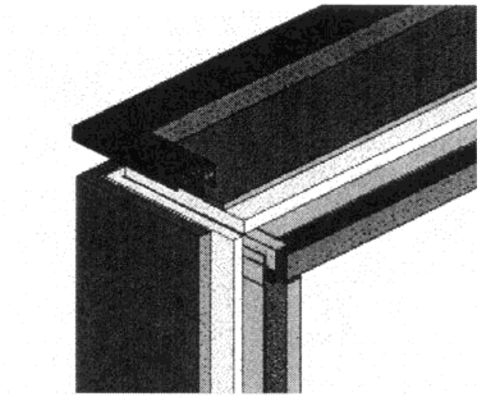

Figure 11: Joint air barrier design units (with all other layers). Note the two parts of the air barrier: the portion overlapping the steel plate is allocated as a rubber membrane while the portion solely on the slab itself is actually allocated by the slab surface.

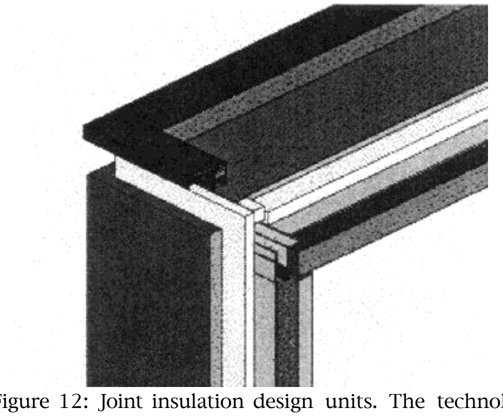

Figure 12: Joint insulation design units. The technology allocating insulation at the joint must make three changes to the current state. First, it must trim the roof insulation to the inside of the cap surface. Second, it must add insulation within the stud spaces of the cap upright. Third, it must extend the wall insulation upwards to the top of the roof insulation.

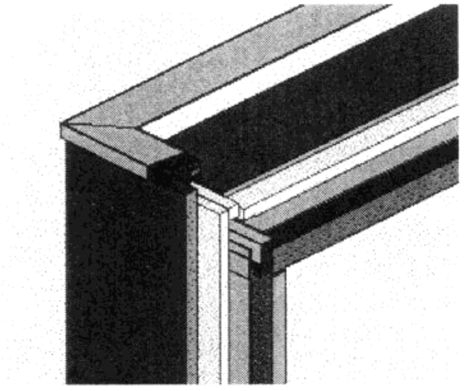

Figure 13: The wall and roof rain/sunscreen are modified by the technology that creates the joint rain sunscreen, which is demonstrated in two stages in this and the next figure. Here, the rain/sunscreen of the roof is trimmed and that of the wall extended. A laser of rubberised asphalt is wrapped around the top of the

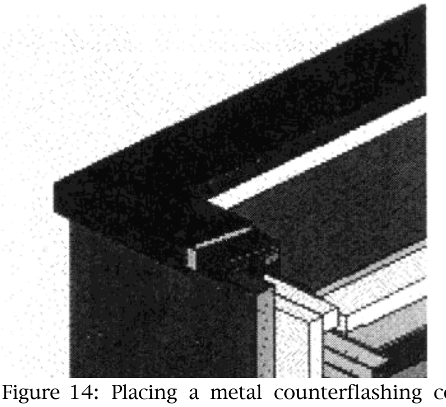

Figure 14: Placing a metal counterflashing completes the rain/sunscreen of the joint. This results in a conceptually complete detail of the wall-roof joint.

3 Three lessons

We infer three key lessons for the use and further development of SEED-Config.

(a) Technologies are function-driven. The recognition part of the enclosure technologies deal mostly with the functional description of a building, identifying allocated geometric parts, but doing little geometric recognition/ matching. In effect, the functional representation acts as an indexing scheme into a design configuration that eliminates most need for extensive geometric search.

(b) Functional units are described dynamically by technologies. The instantiation parts of technologies develop the functional description. They do this because different technologies imply different functional descriptions. Since a main point of SEED is to explore alternatives, the functional unit hierarchy of a problem has to be dynamically bound. An important side-effect of dynamic function definition is that the problem definition is not invariant across a design space-it changes in unrestricted ways.

(c) Enclosure design descends an abstraction hierarchy. Each higher level functional unit is allocated as an abstract description of the enclosure. Lower level function units develop lower level descriptions using the higher level descriptions as arguments, but typically leaving them unchanged. At the end, there exists a hierarchy of representations, from abstract to concrete, each complete at its level of abstraction. For example, the enclosure technologies develop several designs as they proceed - at increasing levels of detail. We first describe a building massing, then an abstract envelope, then subdivide the enclosure into technologically distinct regions, then develop each region in turn as a series of layers, each with a membrane and attachment. This creates a five level hierarchy.

4 Summary

The enclosure technologies are interesting in their own right, as an example of automation of an aspect of building design, and also as a confirmation of the knowledgelevel structures of SEED.

As an example, they point to a radically different kind of architectural grammar that becomes possible with a strong representation of function. This uses much less geometric matching than most published grammars. This does not diminish the need for shape and geometric matching-it only points to a different style of expression that has its domain of application.

These concepts are finding their ways into the ongoing development of SEED, particularly SEED-Config. At the time of writing, we are developing a new kernel for SEED-Config which will have capabilities we describe here as well as others.

5 Acknowledgements

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6 Endnotes

[1] Brand had long professional association with both the Division of Building Research and Public Works Canada.

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