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Elements for spatial reasoning in construction

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Abstract
According to AI techniques we see spatial reasoning, in construction, as generation and solving of goals involving a spatial representation model of buildings defining a rich taxonomy of parts and elements, and spatial relationships between these parts and elements.

We define spatial representation model and spatial relationship from previous experiments in architect knowledge representation and automated surveying. The aim is to enable very abstract and short descriptions of building component assemblies, from designers at drawing-boards or from workers on sites, which can be processed and transformed in basic geometrical properties.

1. Introduction

Spatial representation used in CAD and construction robotics is based on analytical geometry. It does not take into account semantics associated with physical objects and spatial reasoning is restricted to analytical calculus (Crowley.86, Vincent.86, Laumond.88).

Imagine a robot, equiped with telemeters, which is given a task to be performed inside a building. It has to represent its environment. Geometrical representation enables the robot to reconstruct room boundaries but not to identify object types. However, object type identification could enable robots to reconstruct exhaustive geometrical model with a minimum of captured geometrical data ; missing data being inferred through a knowledge base.

On other hand, tasks cannot always be described at design stage. Many decisions concerning action plans have to be taken on site according to spatial relationship between objects and not in respect with absolute coordinates originated from CAD drawings.

The aim of this paper is to enlarge spatial representation in taking account of the very nature of building elements. We refer to architectural knowledge to identify object types and their spatial relationships.

Spatial reasoning was first studied by psychologists - cf Piaget, Lynch among others. Logicians, on their account, focused on spatial reasoning for exploration of spatial environment, such as finding a route in an unknown town (Keepers.78). In AI most research work focused on image recognition. In this paper, we are concerned with spatial assembling of physical objects and tasks involved in building construction. At the difference with psychologists and logicians, we refer systematically to architectural vocabulary and draughtsmen know-how in order to identify concepts involved in spatial reasoning.

2. Spatial reasoning in architectural design

There is an implicit assumption to our approach that it exists a common spatial representation mode and spatial reasoning for design and construction. At design stages, designers handle lines as physical objects - images of existing objects bound to physical laws. Objects are arranged not in absolute coordinates, as in geometrical space but bound by spatial relationships according to their spatial properties. To some extent, designers behave, on drawing boards, as masons on sites.

2.1 Basic taxonomy:

We distinguish, in construction, three kinds of objects: "Architectonic Entities" (AE), "Architectural Views" (AV) and "Architectural Objects" (AO). AE are spatial references, such as: axis, frame, "wall-reference-surface", alignment,...AE's are virtual objects (i.e. they are not physical objects). However, they are very useful for spatial representation and spatial reasoning because they can be directly interpreted in geometrical terms (*) :

Architectonic Entities (AE)	<->	*geometrical elements*
"wall-reference-surface"	<->	*surface*
"alignment"	<->	*vertical plane*
"upright"	<->	*vertical plane*
"run-together"	<->	*horizontal plane*
"reference mark"	<->	*point*
axis	<->	*strait-line*
volume	<->	*volume*
....		

AV's correspond to partial descriptions of objects, according to specific view-points, such as : shape, construction... . AO's are complex objects associated with synthetic concepts, such as : house, wall, room, brick... Morphological properties of AO's can be described by mean of AE's.

For instance, morphological description of a standard wall would be:

line references { 1 axis}
limits { 2 faces, 2 end-faces, seating-course, levelling-course}
volume {parallelepiped}

Problem of corespondence between architectural semantics and geometrical description lays partly in interpretation of objects as geometric elements and partly in interpretation of spatial relationships binding these objects. Among these spatial relationships, in construction, we have identified two main classes : "adjusting" and "composition" .

2.2 Adjusting relationship

Adjusting relationship is used by architects to position objects in connection with others. This is formulated in expressions, such as "a pillar fitted in a wall", to describe for instance the following drawing:

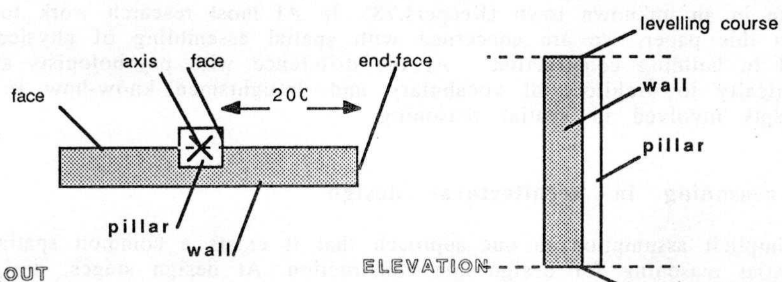

Fig 1: Pillar fitted in a wall

(*) Identified concepts refer to French architectural vocabulary. We could not find specialized dictionary. Our uncertain translations are put between double quotes.

In the same way, at design stages, engineers adjust objects they work on (e.g: casing, ironing, etc...) according to architects objects and references. On building sites, "tracer-men" materialize AE's with blue lines so as to locate correctly fabric-works and finishing works.

Among adjusting relationships we can distinguish three main classes: "chaining relationships", "shaping relationships" and "primitive adjusting relationships".

2.2.1 "Chaining relationships"

introduce a hierarchy between objects: one is the reference, the other is the referenced. For instance, in the following sentence: "the pillar is engaged in the wall", the concerned wall is the reference, the concerned pillar is the referenced. The reference is pre-existent to the referenced. This corresponds to strong sheduling in construction tasks:

-construction tasks
- fabric works {walls, roof...} tasks
- fitting works { joinery; tracery...} tasks
- finishing works {painting, equipement { lavabo...} tasks

On building site, fabric work precedes fitting work, which precedes finishing work. So it is incorrect to say: " wall is adjusted on the sink". On the contrary, one should say: "sink is adjusted on the wall". This applies even during design process: lines representing walls can imply moving of icons representing sinks, not the other way round.

"Shaping relationship":are non-hierarchical spatial relationships. They may be very abstract and laconic, such as in our first example: "The pillar is half-fitted in the wall". However, its geometrical interpretation needs further decomposition in more elementary relationships.

2.2.3"Primitive adjusting relationships":

apply to Architectonic Entities (AE). They are elementary relationships. And for instance, they enable us to expand the "shaping relationship" above as follows:

"The Pillar and the wall are half fitted"
because *:*
- *"pillar's axis is in the "wall-reference-surface"*

and - *"pillar's levelling course" and wall's "levelling course" run together"*
and - *"pillar's "seating course" and wall's seatings course run together."*

In general, "primitive adjusting relationships" express contiguity. But they can also be used to express accurate and fixed measurements (e.g: distance, length, depth, etc.).

ex: "wall-reference-surface" is two meters apart from pillar's face

2.2.4 Geometrical interpretation:

as mentionned previously, architectonic entities can be directly interpreted as geometrical entities. In the same way "primitive adusting relationships" can be interpreted as geometrical relationships.

Let's take the "primitive adjusting relationships", from our previous pillar and wall example: *"The pillar's axis is on the "wall-reference-surface"* .

We can interpret the two architectonic entities as two geometrical entities :

- *wall-reference-surface"* <> *vertical plane*
- *axis* <> *strait line*

We can express the "primitive adjusting relationship" by a geometrical relationship between a plane, for the face's "wall-reference-surface", and a strait line, for the axis.

the pillar's axis is on the "wall-reference-surface"
<> *the strait line belongs to the vertical plane*

2.3 "Composition"

Composition is a fundamental architectural relationship. Thanks to it, architects can link objects as with adjusting relationships, but in addition they can "group" objects to make more complex ones.

The following drawing shows: *A façade composed by symmetry:*

which can be seen as :

- *" a group of: { Wall, "group of windows", "group of doors", stair, caps}*

and - *"all these objects are adjusted on a vertical symmetric axis"*

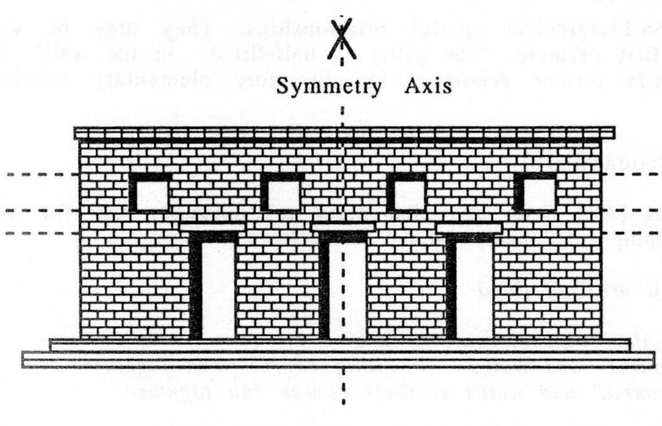

Fig. 2: Symmetric composed facade

3. Spatial reasoning for surveying

Problem, here, is the opposite of the previous one. Instead of expanding abstract and condensed relationships in more elementary ones and ultimately in geometrical properties, we have to reconstruct building models from geometric data.

In a previous paper (Giraud.87) we presented how to use a telemeter plus a theodolite for building surveying. Any point on a plane can be captured (*) and stored on a magnetic tape in spherical coordinates (viz : 2 angles plus a distance). And a survey consists in a collection of points - plus generally observations or diagnosis. However, how to reconstruct a geometric model of buildings from a set of points ?

(*) there are technical limitations, such as: distance cannot exceed 250 m, incidence angle must be inferior to 70°, no measurement is possible on dark colour or on mirror surface).

Using a telemeter, a theodolite plus a handable micro-computer, we can rely on CAD packages to generate drawings, perspectives, quantity bills, etc. However, we have to identify what is surveyed ? and how ?

To that end, we had to conceive a surveying methodology, partly a trade-off between topographics and manual surveying methodologies. That methodology is based on identification of architectural elements to be captured and geometrical assumptions.

3.1 Captured elements:

We cannot have a global and exhaustive view of a building. On the contrary, we have a multitude of partial views from which we have to reconstruct the wholeness. Moreover, some objects are inaccessible or their geometric limits are hidden.

Instead of capturing objects edges and vertices, as in manual surveying, we capture surface boundaries of identified elements. We ultimately came to identify volumes, which are defined by wall surfaces (including floor and ceiling) and elements which are either architectural elements (e.g. bay, niche, beam, post) or fittings (window, radiator, plug, lighting). In most cases, volumes correspond with rooms. Elements are attached to wall planes and are precisely located in space with 3D coordinates.

As a result a building is seen as a collection of volumes and elements. Volumes are captured by their boundary surfaces. Elements are located in 3D space and matched with pre-existent representations stored in a database.

3.2 Geometrical assumptions:

Depending on the technology of building components the accuracy may vary from millimeters to several centimeters. Moreover, texture of a wall surface, joint or splinter may introduce a variation of distance greater than the incertitude on measurement. Exact surveying of a wall surface would require a very fine scanning resulting in a cloud of points. That would be meaningless. Instead what is needed is to identify the shape of the element. For instance a wall surface is assumed to be plane and is surveyed with only three points; same with a cone or a cylinder. Wall surfaces are vertical - unless it is clearly leaning - or at a given height walls have a constant section, etc. As a result, shapes can be defined with the minimum points.

Those assumptions are also extended to compute geometric limits of elements. For instance, we, often, cannot see the ceiling itself and therefore cannot have directly thickness of the floor. That information is inferred through technology assumptions.

Fittings are surveyed individually and their representations are stored in databases. Therefore, what is needed in the survey is only to identify these elements and to locate them in space by a point and attachement to a surface. Recesses or projections on walls and floors are computed by a CAD package (namely: KEOPS). For instance, identification of a window induces a bay in a wall - width of the bay is the window width.

3.3 Points and planes as spatial references:

Surveyed points are related to the telemeter and theodolite origine. A survey needs to move the telemeter and the theodolite. Therefore, it is necessary to link set-ups together in order to compute absolute coordinates. For more convenience on site, we adopted to have indirect links between set-ups by aiming at two same points from two different set-ups or by referring to same wall planes. Surveyings attached to a given set-up are, then, arranged to coïncide common reference points and planes. Here again, we make the assumption that walls are straight and have a constant section at a given height.

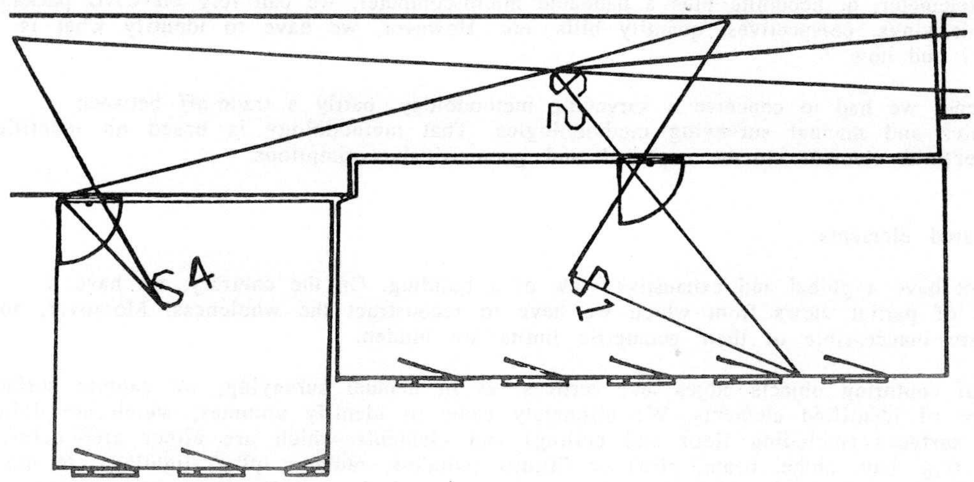

Fig 3: Surveyed data from two set-ups and their binding

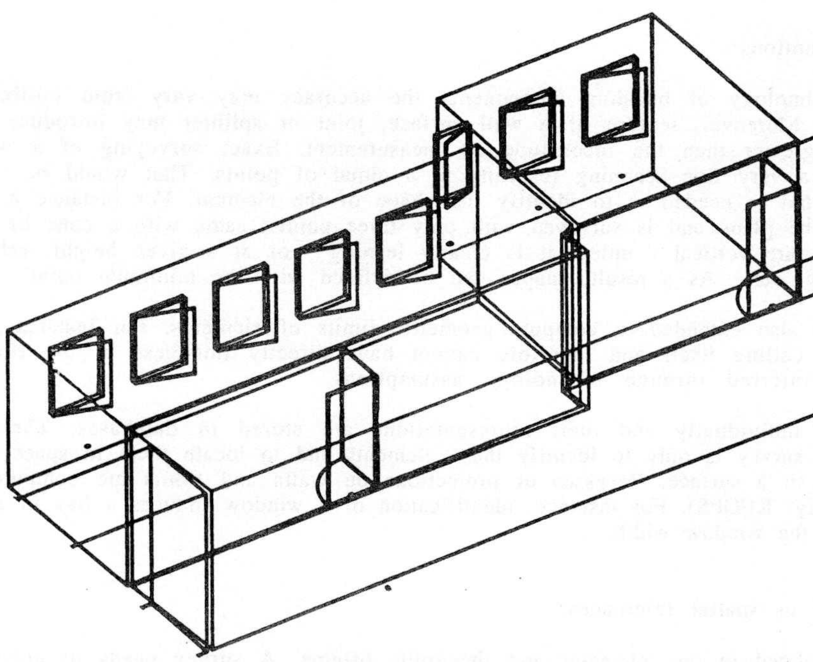

Fig 4: Visualization, on site, of surveyed data

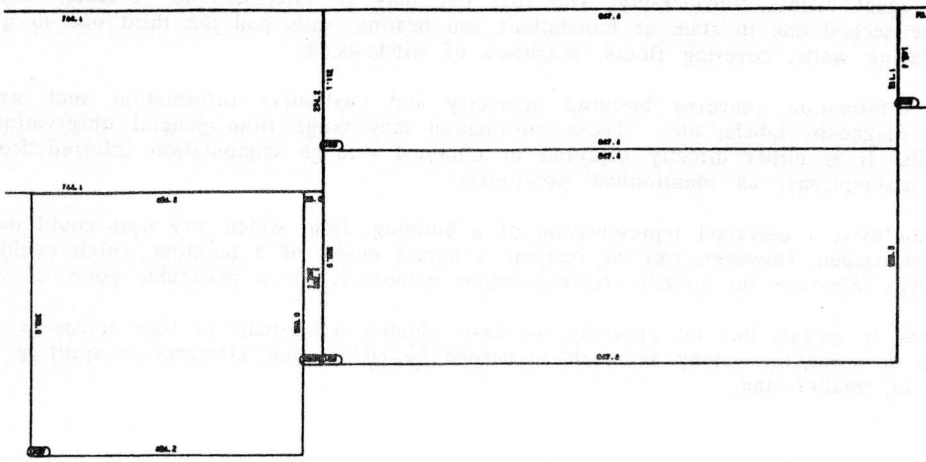

Fig 5: Reconstruction of wall-axis with KEOPS (an architectural CAD package)

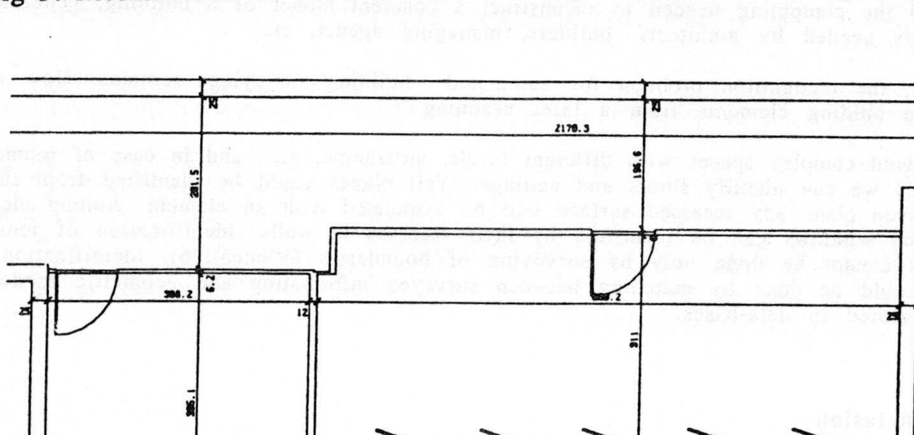

Fig 6 : Reconstruction of building model with KEOPS (an architectural CAD package)

3.4. Possible extension

Reconstruction of building models:

There are as many surveyings as there are tasks. A survey for an architect, a builder or a managing agent differs considerably. The first one may be interested in volumes, architectural details, the second one in state of foundations and bearing walls and the third one in quantity bill for facing walls, covering floors, diagnosis of windows,etc.

Surveyed information concerns building geometry and qualitative information such as functions, diagnosis, labels, etc. These information may range from general observations to fine details. It is either directly captured or obtained through computation inferred from building assumptions, as mentionned previously.

It does not exist a universal representation of a building, from which any user could extract all information needed. However, can we imagine a kernel model of a building which could be used as a unique reference for specific representations elaborated for a particular point of view ?

Up to now, it appears that the approach we have adopted is adequate to laser telemeter and enable us to refine the survey as much as needed by adding new elements or splitting complex elements in smaller one.

Basis for an automated surveying system:

We showed how an operator can use a telemeter to survey a building by pointing at elements which have a pre-existent geometric representation stored in a database, so that a machine can make all the computing needed to reconstruct a coherent model of a building, generate all documents needed by architects, builders, managing agents, etc.

However, the recognition problem for automated building surveyings remains. How to recognize buiding elements from a laser scanning ?

If we avoid complex spaces with different levels, mezzanine, etc., and in case of rooms outlined by planes we can identify floors and ceilings. Wall planes could be identified from their friezes. On a given plane any recessed surface will be associated with an element. Among elements, doors and windows can be identified by their recesses in walls. Identification of remaining elements cannot be done only by surveying of boundaries (Vincent.86). Identification of object types should be done by matching between surveyed information and geometric model of objects stored in data-bases.

5. Conclusion

We have shown how architectural vocabulary and draughtsmen know-how may be used to identify concepts for spatial reasoning. We showed how concepts, such as "adjusting" enable designers to handle graphical objects without knowing exactly their geometric definition and 3-D coordinates, and how these concepts enable abstract topological descriptions of buildings, in a very concise manner. We, also, showed how assumptions on spatial properties of building components enable very fast and economic surveyings.

Results presented, above, constitute elements for spatial reasoning in construction. These results come from a descriptive approach. Implementation, in a computing environment, would require development of a logical formalism. This is an other matter.

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