CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Integrated Construction Planning: A Problem Analysis

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CIFE Working Paper
Number 13

January, 1992

Stanford University

CIFE Center for Integrated Facility Engineering • Stanford University

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Chapter 1

Integrated construction planning: a problem analysis

1.1 Introduction

On June 4 1990, participants in the CIFE project "Integrated Construction Planning" held a one day retreat at Stanford University. This retreat was the conclusion of a series of meetings that had taken place in the preceding months to explore the broad issues involved in construction planning, particularly in the domain of power plant construction.

The purpose of this retreat was also to prepare the second phase of this project, namely the description of a prototype construction planner and possibly a demonstrative realization.

The participants were: **R. Nielsen**, Bechtel corp., **A. Riitahuta**, Tampella corp, Cife fellow, **Prof. R. Levitt**, Department of Civil Engineering, Stanford University, Principal Investigator, **Prof. J-C Latombe**, Department of Computer Science, Stanford University, Principal Investigator. **J-F Rit**, Department of Computer Science, Stanford University, **R. Wilson**, Department of Computer Science, Stanford University, **D. Zhu**, Department of Computer Science, Stanford University.

1.2 Integrated Construction Planning

1.2.1 What

We want to build a construction planner that integrates symbolic, task constraints and detailed geometric constraints. The input of this planner is a complete design of the product. The output is a sequencing graph of tasks. Each tasks is described in terms of the resources used, duration and cost, along with geometric and process specification of how the task will be achieved.

Example: Move beam with a/this crane positioned at this place on the construction site, the put it in place with three men (duration 20 mn).

1.2.2 Why

Geometry has to be driven by a higher level program because the problems it solves are too atomic for construction planning (and arguably any complex, real world activity). Construction planning cannot be formulated as a giant motion planning problem because of non-geometric constraints like sequencing or availability of resources. Constraints that could be formulated in some geometric way, like time and cost constraints, are probably better handled by more ad hoc means because of sheer complexity.

However, geometry is a necessary component of construction planning. Construction involves moving components. So far construction planning softwares have not gone into the description of this motion. Rather, they assume that they know in advance what kind of construction operations can be performed, given the available equipment and the current state of the construction.

This does not mean that the motion of every solid on the construction site has to be computed at the planning stage. For example, building a wall of bricks is a task sensibly described without computing the path of each brick. First, we certainly do not have the computational power and the time to do this. Moreover, all the information may not be available in advance although the symbolic planner can rely on symbolic knowledge.

Geometrical reasoning has other sides than motion planning. We will however concentrate on this central issue in anticipation of our research interests and realization concerns.

We should also notice that the geometric requirements can have an influence that goes beyond enriching the description of a task. If some tasks appear to be too awkward or require too many resources, then the construction method itself may have to be changed

1.2.3 When

Construction Planning can be performed at different stages in the life of a facility.

- At the design stage one must make sure that every component of the facility can be brought to its final place, that machines can circulate on the construction site etc.
- At the construction stage, actual plans must be generated, taking into considerations overlooked or late contingencies.
- At the maintenance stage, components may have to be removed, and new ones brought in that were not known at the design stage. If everything goes

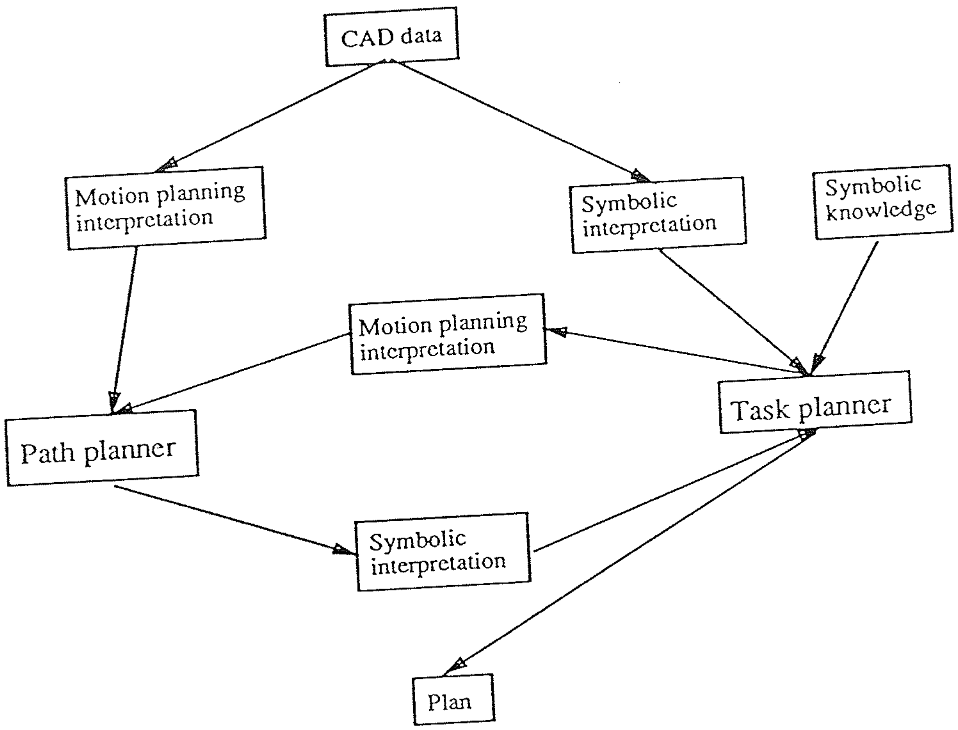

Figure 1.1: General architecture for integrated construction planning

well, new paths for machinery and components will be enough. In the more difficult cases, other components and elements of construction will have to be temporarily removed.

1.2.4 How

Geometric problems need to be precisely defined to be solved. This comes from the "hard core" complexity of these problems which cannot be solved by aggregation of symbolic knowledge (although it helps, like predefined procedures to move a table through a door).

This is why we want to concentrate the geometric capabilities in a module that will accept precise enough requests made by the task level. At this task level, one will have to decide which problems need to be explored in geometrical details.

The geometrical module and the symbolic planner each work with a specific kind of data. Intuitively, one can think of them as, respectively, logical sentences and drawings. Communication between them, as well as with the overall input and output data — the design and the plan —, require interpretation modules that extract symbolic from geometrical data and convert geometrical into symbolic data. This goes beyond simple format conversion, is often extremely difficult and frequently requires human input because it is the only known way to do it. This is why we think that these "interpretation modules" must be explicitly stated in the architecture (fig. 1.1).

The more specific the description of the task is in terms of goal, initial location and environment, the easier the problem is, computationally and conceptually. It is possible to some extent to relax these specifications, like using a goal region instead of a goal position, and it was proposed at the meeting that it would be more efficient and interesting that planning be used during the design process. One would constrain the other gradually, thus dealing with incomplete data. However, this is much more difficult and in contradiction with the affirmation stated earlier that integrated planning needs a complete technical description of the product.

1.3 Scenarios, examples

In order to show demonstrative capabilities of a system, we need to define some sample problems of construction planning. These will be built upon two substrates: one is a simple construction world which will define a kind of vocabulary, the other will relate the problems we will solve to a subset of the power plant construction domain.

1.3.1 Elements: the construction world

The complexity of this world should not, at the beginning, exceed 20 to 30 components. Later, it should be grown to around a thousand parts.

A choice remains to be made. The following is the beginning of a hierarchy that was proposed by the retreat participants.

- Structural components
  - Structure steel
  - Concrete foundations: slabs, walls
- Equipment: tanks, pumps, turbines, fans, heat exchangers
- Connecting equipment
  - pipes: large/small, straight/curved, welded/bolted
  - electrical wiring
  - stairways, corridors
  - Supporting equipment: hangers, cable trays

1.3.2 Subset of Plant

During the retreat, the participants suggested considering a pipe bridge or a turbine deck. The discussion did not go into many more details but was aimed at getting a feeling of the size of such a subset.

It was agreed that such detail was needed to go any further. A. Riitahuta proposed to bring back from Finland the description of a part of the Tampella recovery boiler. We now have the description of a **Smelt spout cooling system** in the form of drawings and CAD data. However, the CAD data must be converted in a format we now do not know how to handle, the description is in Finnish, the system is not mechanically self-standing: support has to be designed or given.

1.4 Research issues

Integrated construction planning addresses many research issues. The retreat participants proposed some that they considered important and that corresponded to their competence. Then they sorted them in three categories depending on interest, need and the potentiality of results.

1.4.1 Immediate issues

These issues would be addressed to build a system within the scope of one year.

Path planning for bringing parts and machines

In theory, this problem must be solved each time something is moved. in practice, it should be addressed when the most important or unusual components and pieces of machinery are moved on the site.

It consists in computing a path from the geometric description of the component moved and the environment. The description of the building components can be obtained from CAD data. If we want to plan paths for machinery, we will also need a geometrical description for it. Efficient path planners have been developed at Stanford, they are still vulnerable to high memory requirements, especially in 3D. We also don't completely know how well they behave in case there is no possible path, which is a case bound to happen frequently if the planner is used to find out whether a motion is possible at all.

Sequencing and scheduling of construction tasks, estimation of duration

1.4.2 Longer term issues

These issues belong to longer term interests of the Principal Investigators.

Grasping and regrasping

Most of the heavy components need to be moved with the help of machinery and in several successive manipulations. These changes are caused by a need to get a different grasp or to change the manipulating machinery. Therefore, we need to know *how* and *when* to grasp.

Support, stability

During the construction, the partially completed building has to stand under its own weight. It must also resist to perturbations like people and machinery moving on the site, components being banged during their transfer and natural elements like wind or earthquakes.

Choice of construction method

1.4.3 Other issues

Temporary structures

This issue is related to the support and stability problem. Very often, temporary structures have to be built to support the partial construction. Independently of support, scaffolding must be built to allow the access of people and machinery to the right places of the construction site. The problem is then to design it, optimize its use and reduce its amount.

Space management for operation and maintenance

This addresses geometric problems caused by maintenance and operation as opposed to construction. First, one must check the accessibility to places where operation or maintenance must be performed. There must be room for people, tools and possibly machinery. In the case of maintenance, it is likely that some components will have to be removed. The problem is then to determine which parts have to be dismantled in order to take away the goal component.

It may also be necessary to find a place where to put the disassembled parts if they are bulky or heavy. The disassembly problem can also have to take into account functional considerations to determine which subsystems must be shut down so that part of them can be removed.

Subassembly identification

Using subassemblies is in general more efficient in the construction process. It allows parallelization in time and space and sometimes a concentration of competence when components can be assembled off-site. In the case of disassembly for maintenance, it is obvious that removing whole subassemblies is a more efficient way.

Identifying subassemblies is a combinatorial problem that must obey constraints of manipulability (bulk and weight), accessibility and mechanical and functional coherence.

Chapter 2

Prototypes of integrated layout construction planning

During the second phase of the project, we focused our efforts on building two prototype systems that put motion planning in a higher perspective than just planning a path. They are: a *layout sequence planner*, which finds ordering constraints on the introduction of objects on a layout, and a *pathway planner* which designs pathway areas suitable or moving objects in a layout.

These systems are not, as was initially envisioned, a prototype for a general, global construction planner for a plant or a complex device. We could not, with the available people and time, have a tight enough coordination and provide the effort necessary to get and process real data from construction companies.

However, the systems address several of the points raised during the retreat. They both demonstrate how a motion planner can be used to solve constructions problems of a higher level. The architecture of these systems can be described in the terms of the more general planner. Figures 2.1 and 2.2 show how the data flow between a path planner and a higher-level symbolic problem solver. The identical structure of the graphs show that we approach in the same way the pathway planner, the layout sequencer and the generic construction planner (the architecture of which is shown on fig. 1.1).

2.1 The layout sequence planner

2.1.1 Problem statement

A 2D layout is specified as a set of objects described with their shapes and their final positions in the layout. The objects are also given an initial position where they "appear". The layout sequence planner must find all the sequences of appearances of objects and must ensure that paths exist to move all the objects from their initial to their final positions.

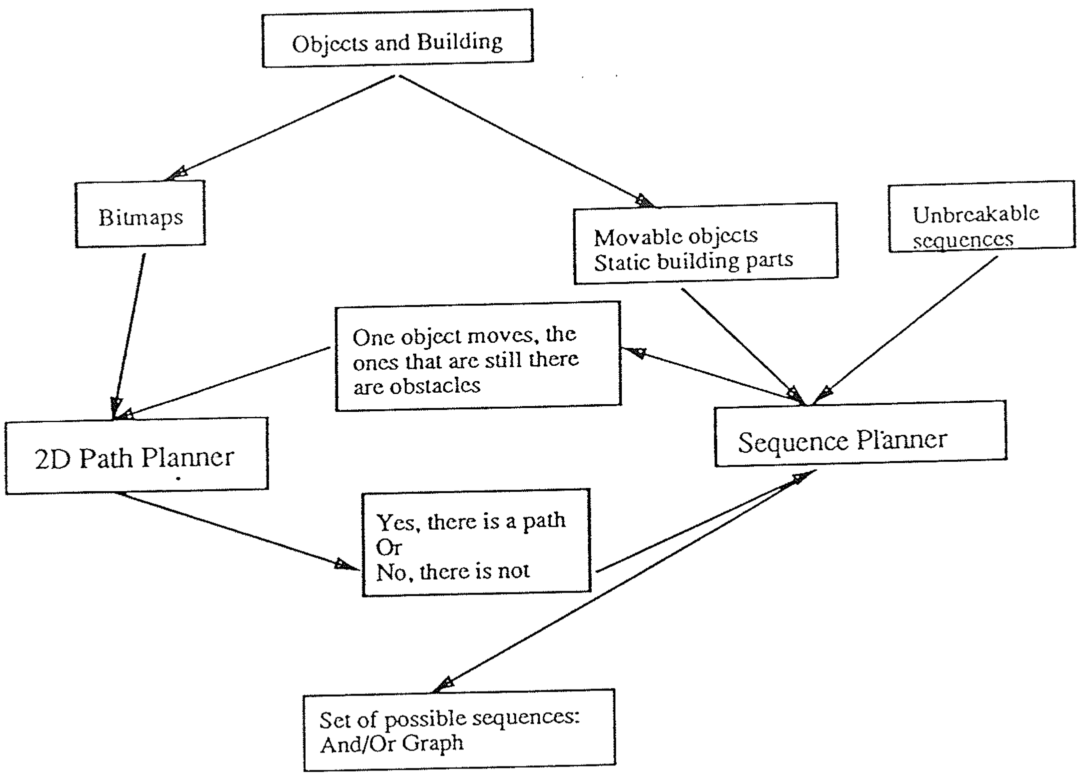

Figure 2.1: Architecture of a layout sequence planner

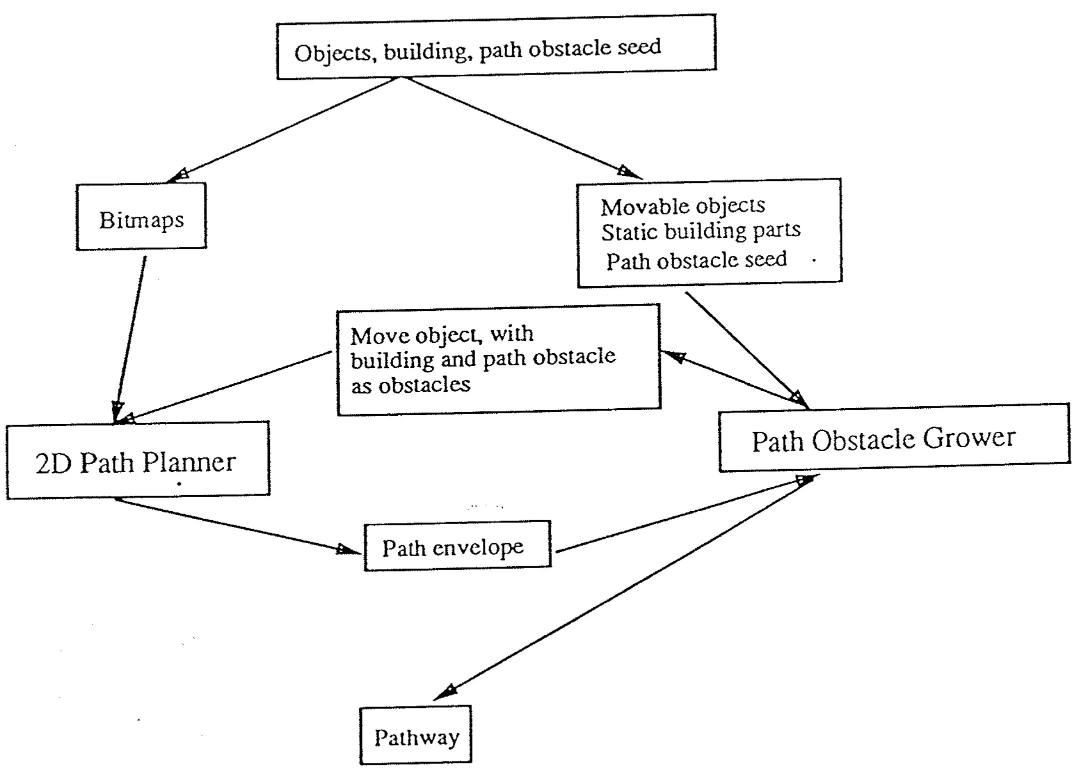

Figure 2.2: Architecture of a pathway planner

An example of a valid sequence, along with the path of each object, computed by the implemented planner is shown on fig. 2.3.

2.1.2 Implementation

We have implemented a layout sequence planner for polygonal objects. The main components of the system are a pre-existing fast motion planner [1] and a sequence planner. The sequence planner is based on concepts developed for the planning of assembly sequences for small mechanical assemblies [2]. Its salient feature is a representation of sets of sequences with a data structure called an And/Or graph, the expansion of which is the core of the plan search.

This planner is the first sequence planner that produces plans involving complex motions. Until now, all published sequence planners considered rectilinear motions, arguing that computing more complex paths was not tractable.

This planner can plan sequences involving up to 15 objects in about half an hour on a 25 Mips workstation. This is of the same order of performance than the other published geometrically oriented sequence planners.

2.1.3 Possible extensions

We can consider two kinds of improvements.

Performance improvements would allow the current planner to run faster on more complex layouts. They involve research on algorithms for sequence planning in general.

Functionality improvements introduce new requirements for the sequence planner. They are generally more oriented towards construction planner and make the problem more complex.

Performance improvements

Besides improving the performance of the motion planner itself, which uses most of the computer resources, substantial improvements can be made to the system by favoring a tighter relation between the symbolic sequence planner and the motion planner. For example, in the current system the motion planner gives a yes-or-no answer to a query on the mobility of an object in the layout. When no path exists, a list of "blocking" obstacles would be very useful to the sequence planner so that he does not query for situations where the blocking objects are still there.

A motion planner that would have this functionality would be very similar to the current one. It would be a little slower because it would have to keep track of "active" obstacles. A myopic view of motion planning does not show any justification for this, but the broader perspective of construction planning does.

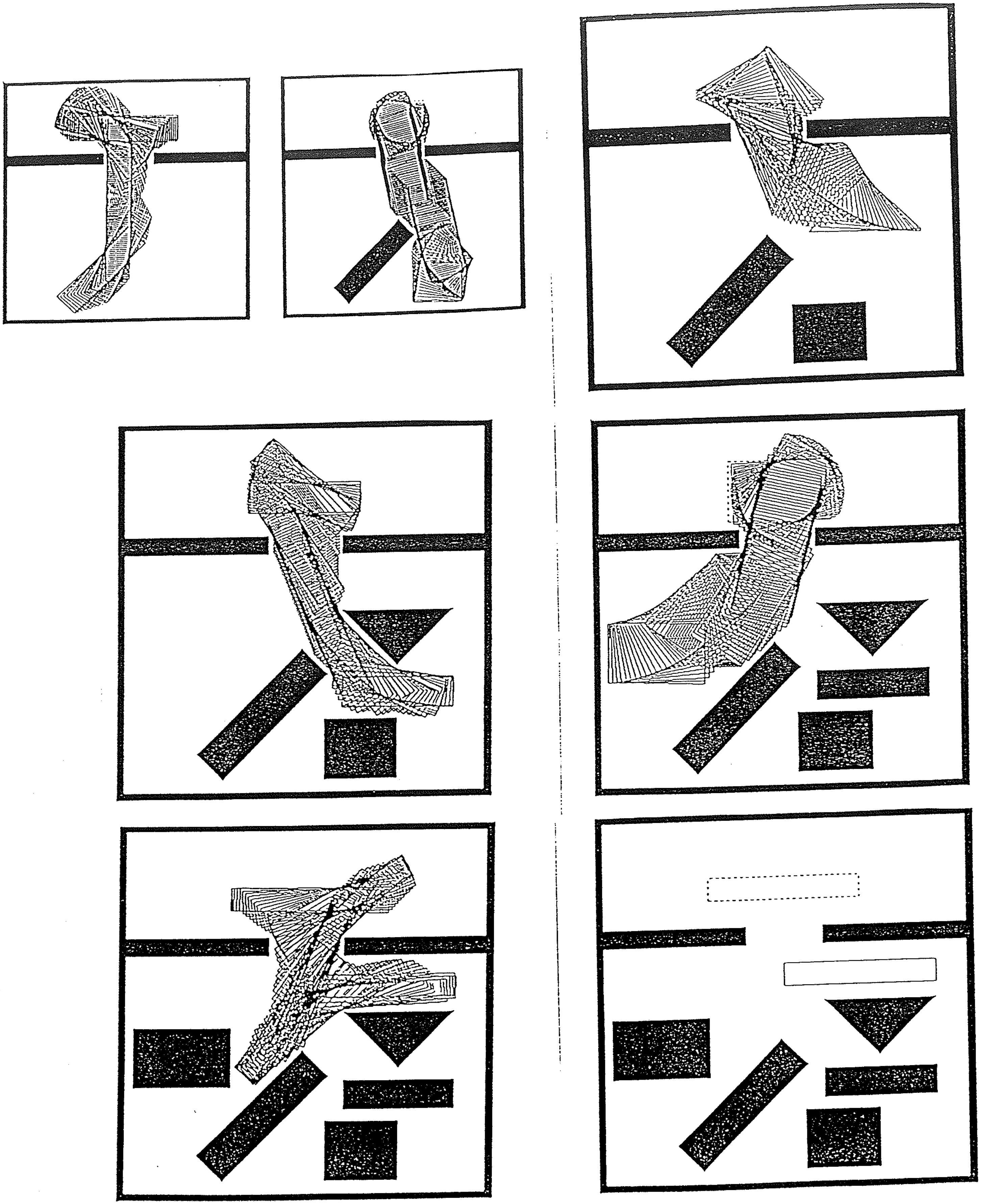

Figure 2.3: A layout sequence

Functionality improvements

Decomposable objects The current planner brings the objects in the layout one at a time. More complex sequences can be considered if the objects are subcomponents of a bigger one. The bigger object could be brought to its final position as a whole or it could be taken apart and the components brought separately. The planner would then decide, based on the feasibility of each transfer, to what degree the bigger object must be decomposed.

The new theoretical aspects of this involve representations that mix the structures implied by sequences and decomposable objects. The And/Or graph representation allows the sequencing of cluster of objects, but it does not take into account pre-existing or preferred clusters like those defined by decomposable objects.

An example of two alternative sequences is shown on figure 2.4.

Movers The description of objects transfer could be enriched. Currently an object flies to its position. It would be more realistic to introduce a "mover" that attaches itself to the object, moves it into position and leaves the building. Along the same lines, an "installer" may have to go to certain positions around the objects, for example to bolt them on the floor, and must have access to these positions.

If every transfer is statically and locally associated with moving and installing, this improvement only makes motion planning harder. If the planner has to decide how and when to group transfers and installations or to find locations for the installer between transfers, the problem becomes harder and begins to have resource allocation aspects.

Figure 2.5 shows a scenario where a rectangular object must be installed next to an L-shaped one. Although both can free fly into position in any order, the rectangular object must be introduced first if the small square shaped installer is to access to the corners.

2.2 The pathway planner

2.2.1 Problem statement

The planner is given a set of obstacles and one moving object, described with their shapes. The object is also given an initial and a final position.

The planner must find a maximal region of the workspace that can be turned into an obstacle while the moving object can still be transferred from the initial to the final position. The remaining free region will be called a pathway for the moving object.

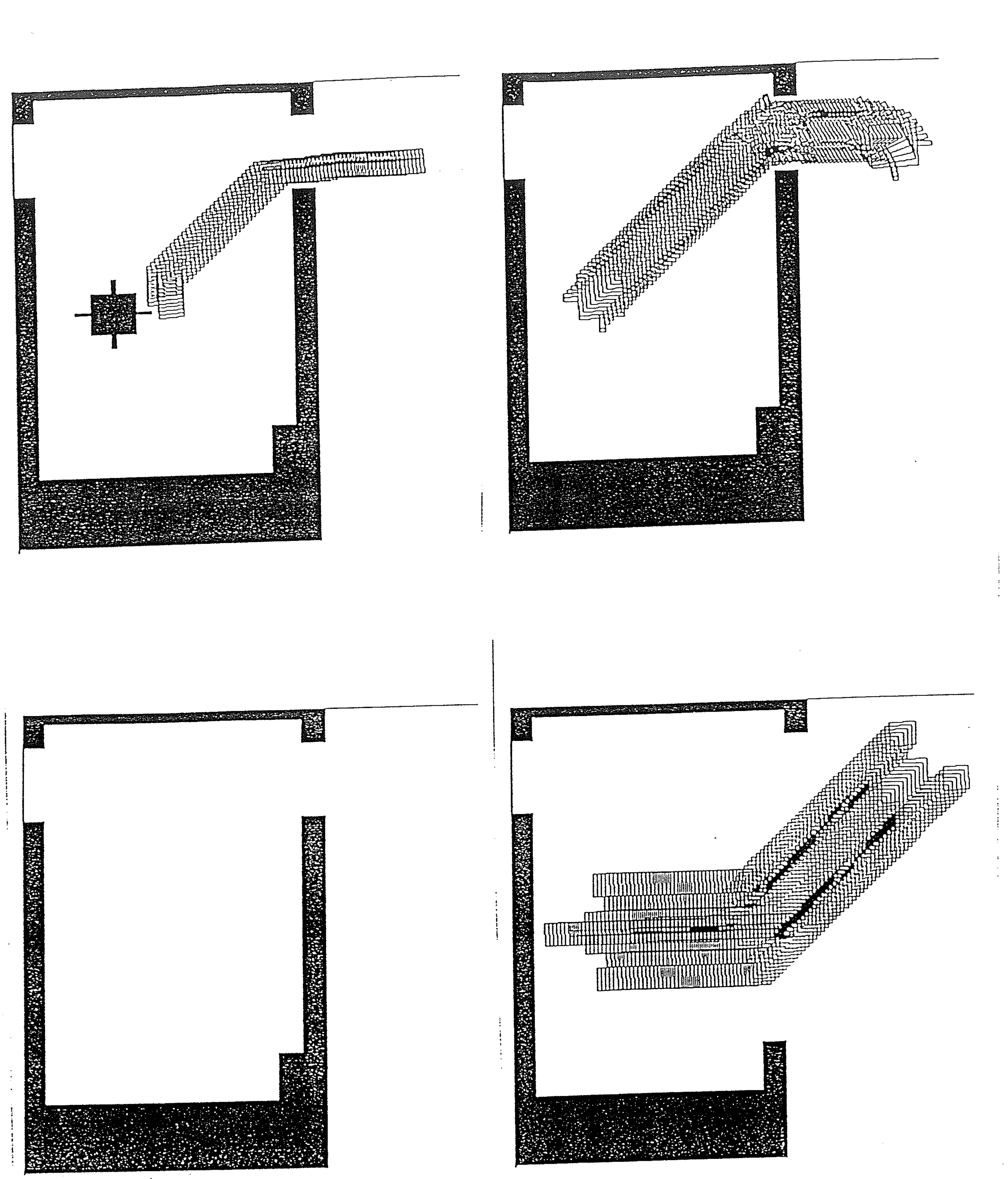

Figure 2.4: This composite object (a table which four attached chairs) must be taken apart to be brought in, unless a section of the wall is removed.

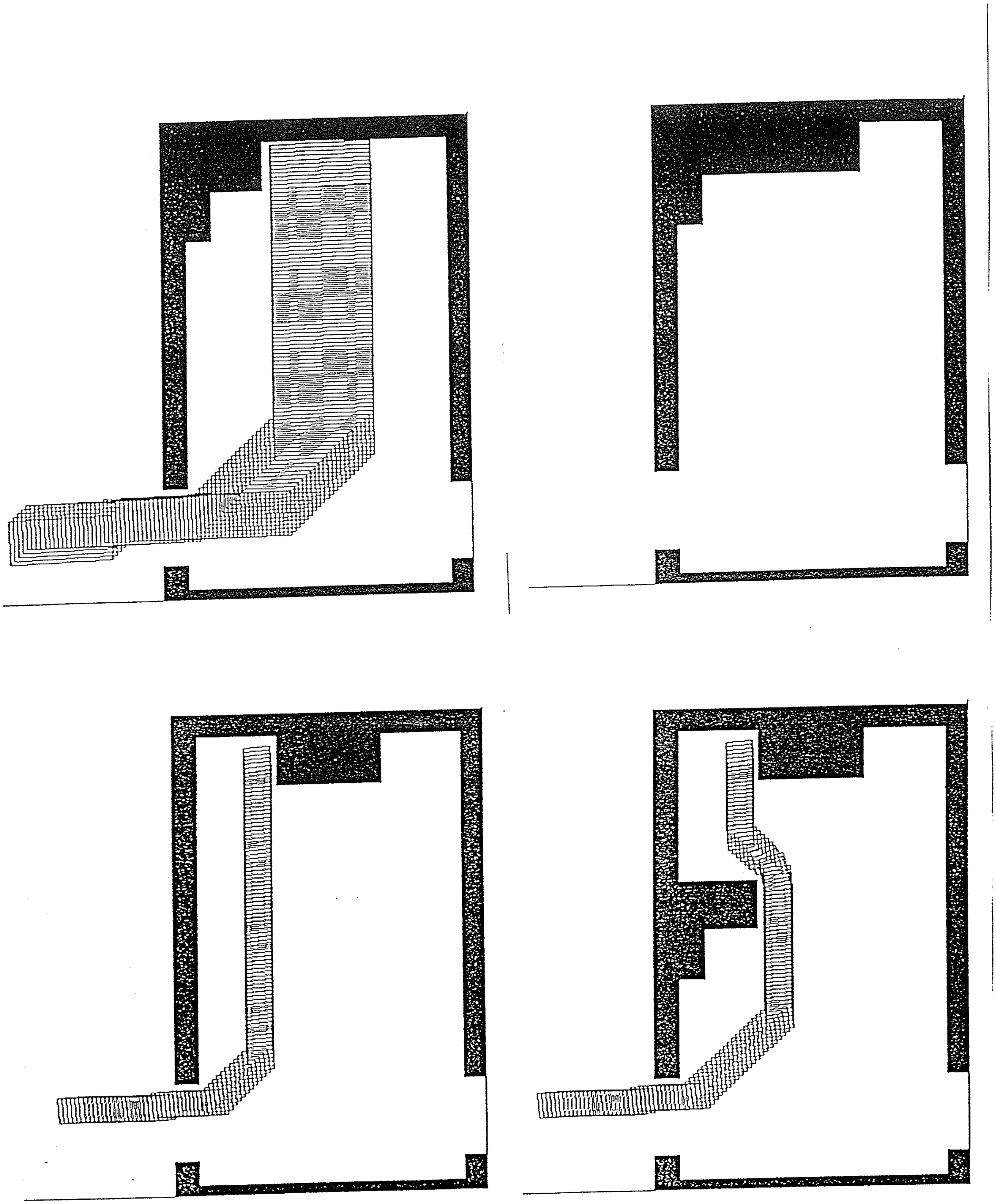

Figure 2.5: If an installer must access to the corners of the rectangular shaped object, the L-shaped one must be introduced after the installation.

2.2.2 Implementation

We have implemented a pathway planner for polygonal objects. This planner requires a virtual polygonal path obstacle seed as an additional input. The system alternatively looks for a path not interfering with any obstacle and grows the path obstacle within the bounds set by the trace of the last computed path. This double search is iterated until the path obstacle cannot grow any more.

Figure 2.6 shows an example of pathway planning for a rectangular object and an L-shaped seed obstacle. In one case the path obstacle has to keep an orthomorphic shape. In the other case, the path obstacle can be an arbitrary polygon.

Examples such as the one shown on this figure require an order of ten iterations and are computed in about ten minutes.

2.2.3 Possible extensions

This planner is still in an early stage. This problem being quite new, the concepts need some clarification, as opposed to the sequence planner which benefitted from a thread of research in assembly planning. For example, the "maximality" of the path obstacle is not obvious. It is maximal in the sense that it cannot grow any more according to the growing procedure and the traces left by the object motion. Both of these criterion are embedded in code and are only vaguely correlated with a maximal area criterion for example.

A second improvement would be removing the need for a user specified seed obstacle. A possible approach is to have the existing obstacles grow. This would probably require improvements in the basic growing techniques, such as allowing several growing polygons — and deciding which ones to grow — and allowing the auto-creation and deletion of vertices on the path obstacles.

Exploring shrinking obstacles approaches would also be worthwhile. This would be the most natural approach to remodeling an existing building. On a more technical side, this would allow failure directed backtracking in the growing approach.

Finally, a pathway is rarely designed for a single object, but rather for a collection of objects. One way to introduce multiple objects while staying very close to the current algorithm could be planning paths for all the objects and taking the union of all the traces as the new constraint for growing path obstacles.

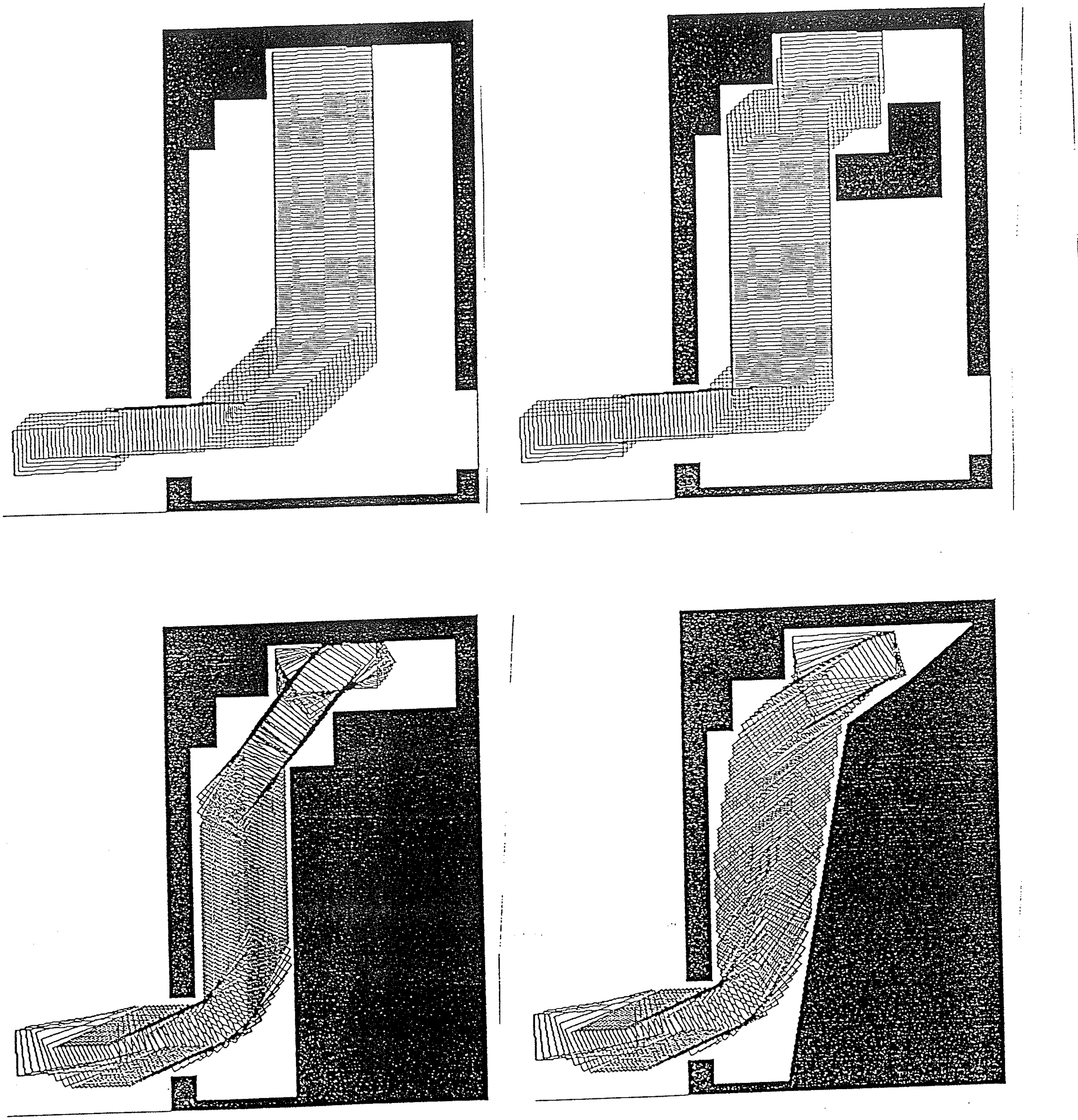

Figure 2.6: An example of pathway planning

Appendix A

Minutes of the meetings

A.1 Feb. 6 meeting

DEFINING THE SCOPE OF THE PROJECT

General Approach

The purpose of this one year project is the design of a new type of system for assistance in construction planning. We will not produce an implemented system. Therefore we should not agglomerate bits and pieces of existing software, but we should come out with a full, consistent and possibly new concept of what CAD of industrial facilities should be.

We allow ourselves the first half of the project to find where the problems are. During a short retreat, we will summarize them and give a first outline of the system. During the second half of the project, we will precise this outline, position the state of the art in this framework and define precise tasks of research and development. These will make the core of a proposal for a CIFE flagship project.

Domain

Since Asko Riitahuta is with us this year, the general consensus is to consider power plant construction.

Theme

The original theme, stated in the CIFE proposal is the integration of "high-level planning" with "geometrical reasoning". High level planning involves the identification of construction tasks and their organization in terms of inclusion and precedence relationships. Geometrical reasoning validates the tasks with respect to the motion planning of machines and components.

Asko Riitahuta and J-C Latombe argue in a draft CIFE technical report that the main problem in power plant construction is to integrate design and construction to reduce the overall length of the project. They propose to recenter the theme of the project on this. Asko Riitahuta thinks that even operation and maintenance training should be integrated. In this perspective, a focus on active parts (pipes, pumps etc.) as opposed to structural parts is proposed, since active parts are present from design to operation.

Format of meetings

We feel that people from the industry should be invited, especially during the first part of the project. The general format would be a short overview of how the problem is seen by the speaker and his company. A discussion would follow, possibly led by people from other companies that would put in perspective what has been said.

Two main areas are possible.

- General design and construction of power plants - Software tools

This will be completed with a presentation of our own research interests and how they can contribute to this project.

A.2 Feb. 20 meeting

BUILDING A POWER PLANT: FROM DESIGN TO OPERATIONS

This meeting was centered around a global overview of the design/building process by Reed Nielsen from Bechtel. [Various comments or reactions by other participants are written between square brackets].

- Conceptual phase - Identify/restate owners needs (what he wants, when) - Identify needed/available construction resources: equipment, personnel. [It was quite a surprise that the availability of big equipment is considered at so an early stage] - Preliminary schedule [grain size? time, number of activities...]

- Design and procurement - Identify system requirements - Decide components - Start procurement

[Up to this point, the general feeling is that decisions draw upon experience and a priori patterns. Probably a good domain for "classic" expert systems. We are more interested in the following]

- Integrate various construction disciplines - Layout [comes AFTER selection of components] - Design & procurement (design to build) - more detailed schedule : erection of major pieces of equipment, start and finish of systems, a few hundred activities.

- Construction phase - detailed construction plan (3 weeks rolling schedule) - bulk installation - startup installation [Bulk and startup installation are two contradictory approaches for detailed construction. The first focuses on achieving maximum efficiency in installing components of a given type, the second focuses on installing complete functional subsystems by given deadlines. Good planning ensures that these two approaches interact harmoniously so that the overall goal of fast construction is attained. The current approach is to build bulk-oriented up to a well chosen point, then complete each system. The general feeling is

that this could be improved by refining the bulk construction in terms of batch nature, size and ordering so that systems installation can be more efficient. This could be done at detailed scheduling level as well as at the layout design phase.]
- redesign [This problem occurs when construction has begun or at least when some construction operations are strongly committed, because of procurement for instance. The cause for redesign can be a new constraint in layout, a new or changed component... The problem is to try to undo the fewest possible things. In particular, the redesign should remain as much as possible within one domain. In any case, the interaction with other domains should not go beyond delaying the schedule.]

- Startup and operations - verify the system operates per specifications - identify deficiencies - interface engineering/construction modifications

- Operations - identify problems - maintenance (what can be removed? how?) - modifications by owner

Other questions raised by the participants

- Will future power plants be big or small?

Both opinions exist. A higher global need meaning big plants, a more diverse need meaning many small units.

The project would have more impact with small units. There would be more of them, so a well thought out standardized methodology would be more useful.

What does small mean anyway? Up to 100 MW is small, but, according to Asko, the size could go up to 300 MW which is not that small.

- Time frame for design and construction:

Conceptual planning can take from 1.5 to 2 years for a big unit.

The whole project takes from 2 to 3 years for a small unit.

A.3 March 13 meeting

BOILER PLANT DESIGN Presentation by Asko Riitahuhta (Tampella)

A. Riitahuhta's presentation consisted in a decomposition of the design process quite similar to the previous presentations of R. Nielsen. It was a little more detailed because of its specificity to boiler plant design when R. Nielsen's presentation was more abstract. See copy of slides for more information.

Interventions and discussion:

AR: The boilers industry is evolving so that R& D is conducted separately and generates more or less standard components that will be used by each project. The existence of such standard components is a constraint but enables a good knowledge of fine details at an early stage of design.

RL: At which level are these components standard? AR: Motors, pumps. They must be able to be shipped. [There is here a fusion of standardization of design and modularity in manufacturing: The components are designed AND built separately.]

JCL: The main thrust in managing an efficient process of design and construction should come from planning. Planning earlier in the process, at a finer level of detail and using bigger pre-designed and pre-manufactured blocks. One problem will be the blending of plans for each subcomponent.

JCL: What kind of machinery is used on the construction site? Cranes, lifters (small cranes), not many pipe manipulation machines because pipe are heavy, bulky and HIGH.

A.4 March 20 meeting

VISIT at BECHTEL

The meeting was divided in two parts. One with W. Ellis as a main interlocutor on power plant design an construction management, the second with J. Melvin on scheduling.

W.ELLIS

Talk restricted to Engineering and procurement type of contracts, as opposed to engineering alone, utility or overseas. Concentration on turbines and boilers (which are the main parts of the plant) as opposed to scrubbers, precipitators etc. Problem of site determination (existing site or new site).

Basic design concepts. Size, operation date. Sometimes the turbine and boiler are already ordered. -¿ 20-30 lines project schedule.

Operating concerns (not from construction domain) + A priori reasoning, experience, what is usually done in the domain -¿ Gross layout = number of silos and location.

Time to lay foundations, to get equipment, to set-up pipes, wires, date of delivery of final system -¿ schedule by backward propagation. (see accompanying documents).

Discussion on use of CAD:

The amount of work put into a CAD system is worthwhile if the model is used all along the life of the project

JCL: How important to you is the capture of design rationale? Not so important. If a decision is questioned it is easier to contact the originator of the decision [it depends on how big/frequent the exchanged information is]. Can be useful for subsequent projects, at cost estimation time for example, but not within one project. One has to be careful with the risk of overloading participants with information [this is as much a problem of how to display information than of what to exchange].

State of art on use of CAD: The building can be designed at the terminal with the pipe system, interferences are checked. Some construction constraints can be checked by moving objects in the model and checking for interferences. The output is stored in a database. 2D drawings are also made although this is not an easy task.

J.MELVIN

I've got this huge book of scheduling procedures. This should be automated.

Problem of construction is accompanied with problem of dismantling. When a major component must be replaced we have a geometrical problem: what must be removed and along which path. If we want to automate this, there is a problem of input (there is rarely a CAD model of an existing building).

A big problem in scheduling is the coordination of professions which have different approaches (construction, electrical...).

In particular, in detailed construction, the order of the tasks is imposed by the information being available only on the real thing. What is done last is what can be designed/redesigned more easily. The problem could be potentially solved on a 3D model but this model would have to be very detailed.

Wants a powerful interactive scheduling tool which can propagate symbolic constraints and handle 50000 activities. A problem is that a geometrical model never exists when scheduling is started.

Size of future plants: in the US: cogen. Overseas: big units.

If the project is a relatively new plant, improved planning technology is more fruitful than on COGEN projects for which existing experience has already reduced the project length.

A.5 April 2 meeting

ASSEMBLY PLANNING a presentation by R.Wilson (Stanford)

The assembly planning problem is: how to generate possible orderings on the assembly of parts or subgroups of parts from the geometrical description of a goal assembly.

All the research in the domain considers small mechanical assemblies. The work presented is restricted to 2D polyhedral assemblies with translational assembly trajectories.

The approach is to accept assembly tasks only when a translational trajectory can be found. Moreover, the partial assembly must be connected and must verify a limited criterion of stability.

This problem is provably "hard" to solve in its entirety. The difficulty is first in finding which geometrical criteria can be computed quickly while having a sufficient discriminating power. Then, the computation of different criteria must be carefully incorporated in the overall procedure of generating all possible orders so that unpromising parts of the solution space are not explored.

For more info on this work, see "Maintaining geometrical dependencies for assembly planning, R.Wilson and J-F Rit, in proceedings of the IEEE International Conference on Robotics and Automation, Cincinnati Ohio, May 1990.

Interventions and discussion concerned the relation of this work to civil engineering.

In both domains, we are interested by constraints related to small batches as opposed to process optimization for large batches. This is justifiable by considering manufacturing of prototypes. It is even more justifiable in civil engineering.

Planning on a partial design: the problem is more acute in CE (civil engineering). According to R.Levitt, beyond a certain level of complexity, the only practical solution is to use prototypes invoked statically or synthesized dynamically.

Stability: Taking into account stability under gravity and insertion forces is difficult. The problem is also there in CE with a variety of influences: wind, quakes, cranes, loads dropping...)

Fixtures: hard to take into account, analogous to scaffolding.

A.6 April 16 meeting

AI FOR CONSTRUCTION PLANNING A presentation by Ray Levitt (Stanford)

This presentation spanned several years of research by R. Levitt on using AI concepts to build tools for aiding construction planning.

Construction planning can be divided in three main domains:

- Planning: generate construction tasks and sequencing constraints - Scheduling: introduce durations, dates and resources for tasks - Project control: Track actual activity progress, interpret past performance data and foresee consumption of resources.

The PLATFORM series of systems address the project control domain.

Platform 1 provides a framework for input of activities coupled with risk factors. The matching of planned and actual schedule allows the detection of actual risk influence on activities and gives prediction a better accuracy.

Platform 2 refines the interface and introduces the concept of "live Gantt charts" which are recomputed interactively when the constraints are changed.

Platform 3 introduces decision analysis concepts. The execution of each activity is subject to some external factor, allowing the development of a lattice of possibilities generating several scenarios with their accompanying schedules.

Ref (?)

The OARPLAN system adresses the planning domain.

It synthetizes plans using a constraint-based approach and data derived from a CAD system.

OARPLAN allows the definition of hierarchical construction objects. The planification of these object is done independently at first. In a second phase, subplans are integrated.

OARPLAN also addresses the problem of repeated cycles of operations. It can identify sequences and merge them into a higher level activity which is planned more efficiently eventually.

OARPLAN also deals with uncertainties by allowing the introduction of alternatives.

The system is able to generate correct plans of up to 100 activities in minutes.

Reference: OARPLAN: Generating project plans by reasoning about objects, actions and resources. Adnan Darwiche, Raymond Levitt and Barbara Hayes-Roth. AI EDAM journal (1988) 2(3).

The discussion was mainly centered on getting a better knowledge of OARPLAN to understand its limitations since its achievements seemed so great. The two main problems are an inability to deal with (choose amongst) conflicting constraints and the fact that physics and geometry must be input by hand. The system uses geometric information but does not process it.

A.7 April 30 meeting

MOTION PLANNING Jean-Claude Latombe (Stanford) PIPE LAYOUT David Zhu (Stanford)

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[1] S. Quinlan and M. Yim. *The Quinlan Yim Path Planner.* Undocumented C code. Robotics Laboratory, Department of Computer Science, Stanford University. 1990.

[2] R. Wilson and J-F Rit. *Maintaining geometric dependencies in assembly planning.* in Computer-Aided Mechanical Assembly Planning, L. Homem de Mello and S.Lee editors, Kluwer Academic Publishers, to appear in early 1991.