

DEVELOPMENT OF VIRTUAL AND REAL-FIELD CONSTRUCTION MANAGEMENT SYSTEMS IN INNOVATIVE, INTELLIGENT FIELD FACTORY

PART 2: DEVELOPMENT OF VIRTUAL CONSTRUCTION FIELD

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Abstract: Prototype system of virtual construction field was developed in this study. Making the production plan of architectural construction was attempted by using the system. As a result, it was confirmed that the virtual construction field was effective to the making of the production plan.

Keywords: construction management, planning, construction simulation, virtual reality

1. INTRODUCTION

The site manager execute repetition works of make the construction plan, extract the potential problem, and improve the plan. The virtual construction field supports the execution of this repetition works. The problem included in the construction plan can be found by examining the plan on the virtual construction field before starting of real construction.

In this study, the prototype system of the virtual construction field was made. Making the production

plan of architectural construction was attempted by using this system. As a result, it was confirmed that the virtual construction field was effective to the making of the production plan.

This research is a part of the result of "Research of Innovative, Intelligent Field Factory (IF7)" which is one of the research projects in IMS program[1].

2. VIRTUAL AND REAL-FIELD CONSTRUCTION MANAGEMENT SYSTEMS

In the IF7 project, Virtual and Real-field Construction Management Systems (VR-Coms)[2,3] were proposed to improve productivity and the safety of the construction site. Figure 2-1 shows the schematic view of the VR-Coms.

The VR-Coms is composed of real construction field, virtual construction field and the information management system that treats information generated by both construction fields. The upper row of Figure 2-1 shows the concept of virtual construction field. In this world, information technology is made good use of and information on the building design and the scheme of execution is generated before real construction is started. On the other hand, the lower row shows the real construction field. Here, parties concerned necessary for constructing the reality are shown, such as construction management office, site factory, a special construction trader, materials trader, an equipment trader, a machine parts trader, and architect offices.

Experienced and skilled workers review and modify all construction plans and schedules before the implementation of them. Typically, an iterative procedure is taken to develop solution to accommodate resource constraints, including the workers and equipment involved in the project. In this iterative process, alternatives are generated and tested for feasibility. Further improvements or detection of potential problems are examined to generate new alternatives. This iterative generate-and-test strategy can be applied to evaluate alternative plans and schedules until a satisfactory plan with an appropriate schedule is obtained.

The information management system observes the virtual and real construction fields. This system informs the site manager when the problem is found. The site manager remakes the plan and confirms it in the virtual construction field. And then, the plan will be implemented in the real field.

3. PROTOTYPE SYSTEM OF VIRTUAL CONSTRUCTION FIELD

To make the virtual construction field in the computer, each state of process, cost, quality and safety should be able to be simulated numerically. The process was paid to attention among these in this research. Especially, we gave priority to simulating the production situation of the construction site.

To develop the virtual construction field, computerized environment as shown in Figure 3-1 was build up within the School of Business Administration, Aoyama Gakuin University.

The prototype system of the virtual construction field composed of a design function, a planning and scheduling function, a production simulation function, and real-time based construction management support function.

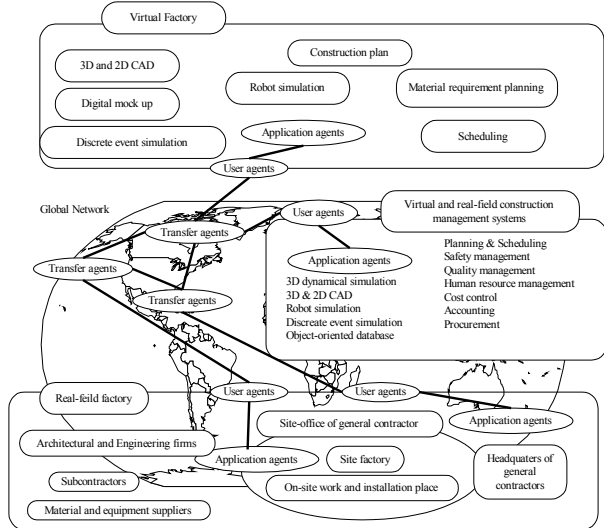


Figure 2-1 Schematic view of the VR-Coms

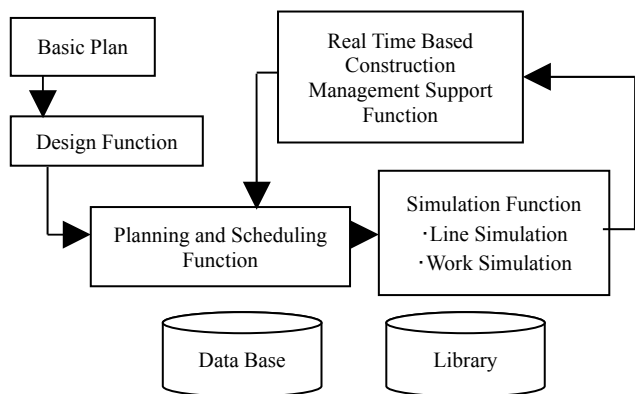


Figure 3-1 The Computerized environment to develop the virtual construction field

The role of the design function is to make two dimension drawings, and to make building model which will be used in the construction planning and the execution of virtual construction simulation. The building model contains not only three dimension shapes but also the attribute of materials that compose the building and the data of the amount and cost, etc.

The objective of planning and scheduling function is to make the construction schedule based on the network diagram, the time required each work and the restriction condition of building construction project. This function makes the process plan over the entire construction project. Moreover, the daily work schedule and the work plan of the construction machines should be able to be made by this function.

The line simulation function is used to simulate material flow in the construction site. The purpose of the line simulation is to confirm whether the construction schedule generated by scheduling function is actually executable. Moreover, this forecasts whether an undesirable phase appears or not during in the construction of building.

The work simulation function creates virtual construction environment in virtual world. We will be able to find potential hazards latent in the construction plan being considered and to evaluate productivity.

The purpose of real-time based construction management system is that manufacturing overhead

reduces and bears the third profit. The real-time based construction management system should correctly display the situation of the construction site to the site manager.

The arrow connected horizontally in the box where the function name was written shows the direction of the data flows in Figure 3-1. The arrow connected with the vertical direction shows the addition of the restriction condition to the function. The actual data are transferred between functions via the database.

In the library, there are models used by the construction simulation. Figure 3-2 shows examples of the construction machine models in the library.

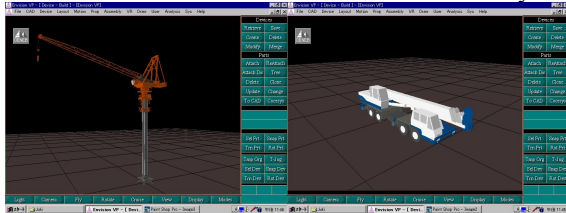


Figure 3-2 Example of construction machine models

The production situation of the construction site can be numerically simulated by the line simulation function. Moreover, the work situation of the site is simulated by the work simulation function. We use Envision [4] and Quest [4], which DELMIA had developed, to construct the simulation function.

4. CASE STUDY ON COFFEE-TABLE TYPE OF CONSTRUCTION METHOD

4-1 Coffee-table type of construction method

The construction of the multi storied apartment dwelling house with coffee-table type of construction method [3] was adopted for the test case. The coffee-table type of construction method is a new construction method, which the IF7 project proposed.

Figure 4-1 shows a typical form of coffee-table module. Coffee-table modules composed of 4 pillar and 4 beams are pre-assembled on the ground in this method. The modules are lifted and piled up to make the building.

Figure 4-2 shows the shape of 16-story apartment building used for the test case. Each floor of this building is divided into eight coffee-table modules. Each floor will be assembled in two days. That is, assembly and the installation of four coffee-table modules per day will be done. Figure 4-3 shows the time distribution for each assembly stage per module unit.

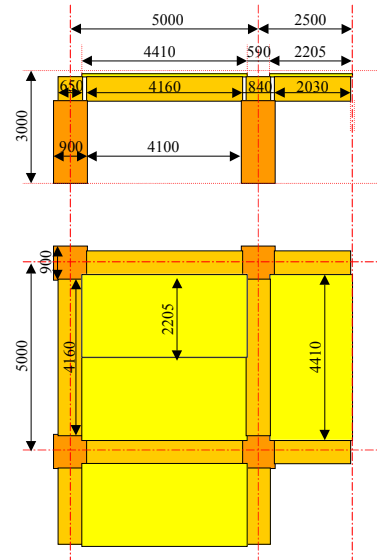


Figure 4-1 Typical form of coffee-table module

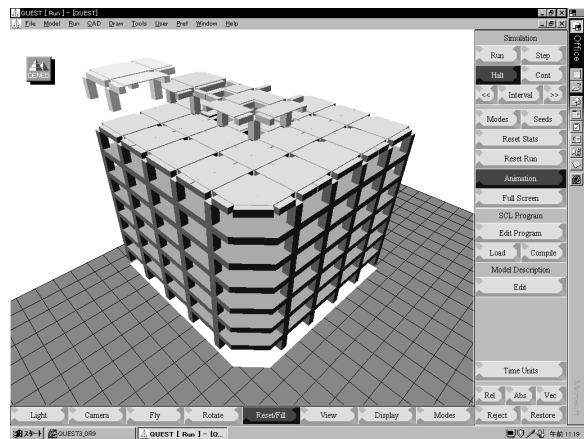


Figure 4-2 Building used for test case

| | Start | 10 min | 20 min | 30 min | 40 min |
|-------------------------|-------|--------|--------|--------|--------------|
| Allocate Hoist Traveler | 5 min | | | | |
| Four Columns | 8 min | 13 min | | | |
| Two Girders (X) | 4 min | 17 min | | | |
| Two Girders (Y) | 6 min | 23 min | | | |
| Four Floors | 8 min | 31 min | | | |
| Connection | 5 min | 36 min | | | |
| Take Shelter | 5 min | 41 min | | | |
| Move, Tie, Hoist | | | | | After 41 min |

Figure 4-3 Time distribution for each assembly stage per coffee table module

4-2 Construction planning for layout of field factory

The site factory to assemble coffee-table modules and the transportation system to pile it up are necessary in construction site to perform this construction method.

The field factory layout plans such as the site factory and the tower crane are made by the planning function in the prototype system. And the plan is

passed to the simulation function. Figure 4-4 shows the example of the field factory where coffee-table type of construction method was used.

4-3 Site factory to assemble the Coffee-table modules

The composition of site factory is shown in the upper part of Figure 4-4. This site factory is composed of the loading area, the buffer area, and the assembly area of the module.

Parts that brought in the loading area are transported to the buffer area with hoist cranes. That is, parts carried into the loading area by truck are lifted up to the hoist crane. Afterwards, parts are transported horizontally by the hoist crane and are put on the buffer area.

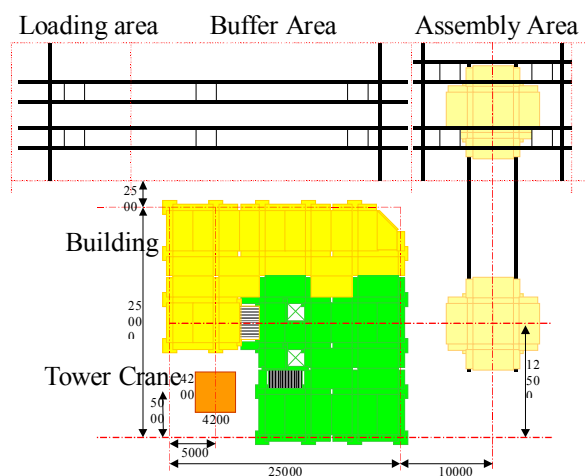


Figure 4-4 Construction planning for layout of construction site

On the other hand, parallel arm cranes assemble coffee-table modules. The parallel arm crane goes to the buffer area to take necessary parts. At this time, a parallel arm crane transfers to the movement rail in the buffer area from the movement rail in the assembly area. A parallel arm which takes parts in a buffer area returns to the movement rail in the assembly area again and moves to the position where parts are assembled.

This site factory goes in the loading function and the transportation function with the same device. The purpose of this is to reduce the number of composition elements and to reduce cost.

This is a kind of site factory, which has the random access buffer. It is a difficult point of this site factory to put parts under transportation on the ground.

4-4 Purpose of the work simulation

To achieve the virtual construction field, each side of the safety, the cost, the process, and the quality in the construction should be able to be numerically simulated. The IF7 project aims at the development of the virtual construction field where the process and safety can be simulated.

The purposes of the work simulation are the following.

(1) Make the plan.

It is included to decide the following items,

- (i) Number of site factory necessary for construction,
- (ii) Layout of site factory in the construction site,
- (iii) Size of the buffer,
- (iv) Number of transportation lines of each site factory,
- (v) Work procedure,
- (vi) Transportation route of parts which have long dimension, etc.

(2) Generate the data necessary for line simulation.

The time need to assemble a coffee-table module can be found by simulating the movement of site factory. Next, it is confirmed whether the assembling time of each coffee-table module satisfies the construction process in the building by the line simulation. If the assembly time does not content the construction process, operation procedure of site factory should be changed.

(3) Become the test bed of the information management system.

The work simulation function is used to confirm the data necessary for controlling construction is observed without omission. Moreover, the work simulation function is used to confirm the information management system operates correctly.

(4) Explain the work procedure.

The simulation expresses knowledge in the visible shapes. Using the visible shape with use of the simulation technology become easy to transmit knowledge. The construction simulation can accurately transmit knowledge, which affects construction to the designer, the enterprise person, the worker, and the inhabitant around, etc.

4-5 Purpose of the line simulation

The following items can be examined by using the line simulation of the coffee-table type of construction method,

- (1) Through put,
- (2) Capacity of temporary depository and its operation,
- (3) Concerning the order of turning on materials and turning on time,
- (4) Whole layout of construction site including site factory,
- (5) Estimation of influence by disturbance and examination of countermeasures.

The construction schedule from the scheduling function and the site layout plan generated from the design function are necessary to execute the line simulation. The line simulation function outputs the following results,

- (1) Construction site layout,
- (2) Presumption value of through put,

- (3) Storage capacity and its operation method,
- (4) The order of turning on materials and turning on time,
- (5) Countermeasures against turbulence.

4-5 Example of work simulation

The operation plan of the hoist cranes in the site factory was made with Envision. The composition of simulated site factory is shown as follows,

- (i) Parallel arm cranes: 2,
- (ii) Hoist cranes: 3,
- (iii) Movable rails in assembly area: 2,
- (iv) Movable rails in buffer area: 3.

These elements were assumed to have judgment abilities, such as the route planning function and the collision avoidance function, etc.

Using the design function makes the shape data of parts, which compose the building. Simulation model such as the site factories and the tower cranes are made beforehand and are stored in library.

Transportation and assembling operation of hoist and parallel arm cranes to make one coffee-table module were simulated at the last fiscal year. Figure 4-5 shows the screen executing the work simulation.

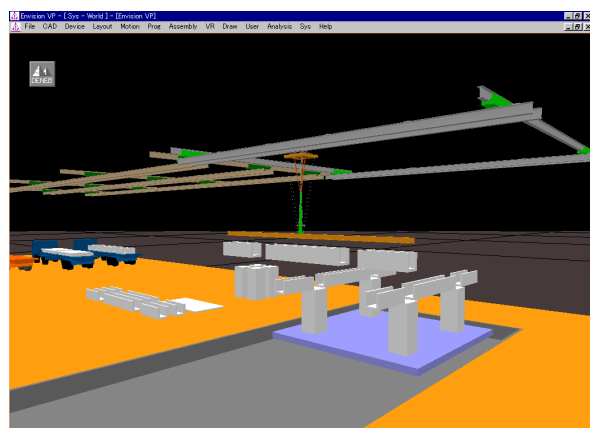


Figure 4-5 Work simulation of site factory to assemble the Coffee-table module

4-6 Example of production line simulation

The production plan is made by the scheduling function and the data is transferred to Quest, which is a discrete event simulator. The first step simulation is executed based on the original plan, the result is examined, and then, the project plan will be improved.

Carrying of materials, assembly of modules, vertical transportation of modules, and installing works of modules should synchronize mutually in the construction site. In the site factory, the operation plans of the hoist cranes, which transport parts, are necessary.

The production situation of the construction site was simulated with Quest. Repeating generation and

test of the production plan could generate the production plan, which satisfy various construction conditions.

(1) Line simulation model

The apartment dwelling house of 16 stories use in the case study of this year is the same as last fiscal year. The division of the module of each floor is also similar to the last fiscal year. This building was divided into three areas from the 1st floor and the 2nd floor to the 7th floor and the 7th floor or more. It was assumed that the same parts (pillar, beam, and floor) could be used in each area.

Two PCa factories (A, B) were installed in simulation model. This simulation does not include the PCa manufacturing process in the factories. All PCa materials will be generated at the beginning of simulation. The factory is connected with the construction site with the usual route and the urgent route. Parts that became failures at the delivered inspection are returned to the PCa factory. Repaired parts are returned to the construction site through the urgent route.

The simulation model of the construction site is composed of the inspection area of the PCa material, site factory, tower crane, and a building under constructing. The site factory is composed the loading area, the buffer area, the assembly area, and the truck to draw out the coffee-table module from assembly position to sideways.

(2) Method of inputting simulation scenario

The simulation scenario was built in the simulation program in the last fiscal year model. Therefore, it was difficult for user to change the simulation scenario. In the model at current year, the simulation scenario is written in the data file. Therefore, the user can operate the content of the simulation by editing the data file. Table 4-1 shows the data file to operate the simulation scenario.

Table 4-1 Data files of simulation scenario

| | |
|---------------------|---|
| Built order list | Piling order of Coffee-table modules |
| Assembly order list | Order of assembling each Coffee-table module |
| Shipment list | List of dispatching trucks, departure time, arrival schedule time, and arrival time |
| Transportation list | Product number of material loaded by each truck |
| Turbulence list | Setting of breakdown of hoist crane |

(3) Setting of turbulence

Three kinds of following turbulence were treated,

- (i) Arrival delay of transportation truck,
- (ii) Failure of PCa material,
- (iii) Breakdown of hoist cranes.

The arrival delay of the transportation truck is set at the arrival time included in the shipment list. The truck where only the schedule time was input in the shipment list

arrives at the schedule time. However, the truck where the both schedule time and arrival time were input will exceed the schedule time and arrive at the arrival time.

The failure of the PCa material is specified with the fail flag in the transportation list. That is, if the fail flag is stood in a specific material, the material becomes a failure in the receiving inspection at the loading area.

The material, which became a failure, takes back to the factory once and is transported to the site again after repair. The transportation of the material after repairing is put in the shipment list, too.

The breakdown of the hoist crane specifies the breakdown beginning time and the return time in the turbulence list.

(5) Output data file

Table 4-2 shows the output data file of the line simulation. The product number and the material number of the PCa material that became a failure are output to the failure log file. The completed number of the module and the completion time are output to completion time log file. Name of the broken hoist crane, break down time, and the restored time are output to the breakdown log file.

Figure 4-6 shows the screen while the line simulation is executed. Table 4-3 shows the part order of delivering the PCa material obtained by repeating the simulation. The production of coffee-table modules that satisfy the construction process can be achieved with carrying the material to the site factory in this order.

Table 4-2 Logging files

| | |
|---------------------|--|
| Failure log | Product number, material number of parts, which became failure and time when failure occurred. |
| Completion time log | Module name and assembly completion date. |
| Breakdown log | Hoist number, breakdown time, and restoration time. |

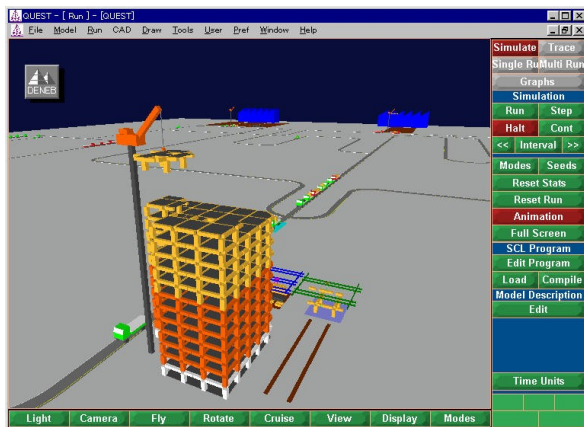


Figure 4-6 Example of line simulation of field factory that use the Coffee-table type of construction method

Table 4-3 Order of delivering the PCa materials

| truck # | Product number of material loaded by each truck | | | | | | | |
|---------|---|---------------|---------------|---------------|---------------|-------------|-------------|--|
| 1 | f(1)_ch2_c1 | f(1)_ch2_c3 | f(1)_ch2_g1 | f(1)_ch2_g3 | f(1)_ch3_c1 | f(1)_ch3_c3 | f(1)_ch3_g1 | |
| 2 | f(1)_ch2_c2 | f(1)_ch2_c4 | f(1)_ch2_g2 | f(1)_ch2_g4 | f(1)_ch3_c2 | f(1)_ch3_c4 | f(1)_ch3_g2 | |
| 3 | f(1)_ch2_f1 | f(1)_ch2_f2 | f(1)_ch2_f3 | f(1)_ch2_f4 | f(1)_ch3_f1 | f(1)_ch3_f2 | | |
| 4 | f(1)_ch3_g3 | f(1)_ch4_c1 | f(1)_ch4_c3 | f(1)_ch4_f1 | f(1)_ch4_g3 | | | |
| 5 | f(1)_ch3_g4 | f(1)_ch4_c2 | f(1)_ch4_c4 | f(1)_ch4_g2 | f(1)_ch4_g4 | | | |
| 6 | f(1)_ch3_f3 | f(1)_ch3_f4 | f(1)_ch4_f1 | f(1)_ch4_f2 | f(1)_ch4_f3 | | | |
| 7 | f(1)_ch4_f4 | f(1)_ch4_f5 | f(1)_ch5_f1 | f(1)_ch5_f2 | f(1)_ch5_f3 | | | |
| 8 | f(1)_ch5_c1 | f(1)_ch5_c3 | f(1)_ch5_g1 | f(1)_ch5_g3 | | | | |
| 9 | f(1)_ch5_c2 | f(1)_ch5_g2 | f(1)_ch5_g4 | f(1)_ch5_g5 | | | | |
| 10 | f(1)_ch5_f4 | f(1)_f1_f1 | f(1)_f1_f2 | f(1)_s1_s1 | | | | |
| 11 | f(1)_ch6_c1 | f(1)_ch6_c3 | f(1)_ch6_g1 | f(1)_ch6_g3 | | | | |
| 12 | f(1)_ch6_c2 | f(1)_ch6_c4 | f(1)_ch6_g2 | f(1)_ch6_g4 | | | | |
| 13 | f(1)_ch6_f1 | f(1)_ch6_f2 | f(1)_ch6_f3 | f(1)_ch6_f4 | f(1)_ch6_f5 | | | |
| 14 | f(1)_ch7_c1 | f(1)_ch7_c3 | f(1)_ch7_g1 | f(1)_ch7_g3 | f(1)_ch8_c1 | f(1)_ch8_c3 | f(1)_ch8_g1 | |
| 15 | f(1)_ch7_c2 | f(1)_ch7_e4 | f(1)_ch7_g2 | f(1)_ch8_g4 | f(1)_ch8_c2 | f(1)_ch8_c4 | f(1)_ch8_g2 | |
| 16 | f(1)_ch7_f1 | f(1)_ch7_f2 | f(1)_ch7_f3 | f(1)_f2_f1 | f(1)_f2_f2 | | | |
| 17 | f(1)_ch7_f4 | f(1)_ch8_f1 | f(1)_ch8_f2 | f(1)_ch8_f3 | f(1)_ch8_f4 | | | |
| 18 | f(1)_ch8_g1 | f(1+1)_ch1_c1 | f(1+1)_ch1_c3 | f(1+1)_ch1_g1 | f(1+1)_ch1_g5 | | | |
| 19 | f(1)_ch8_g4 | f(1+1)_ch1_c2 | f(1+1)_ch1_c4 | f(1+1)_ch1_g2 | f(1+1)_ch1_g6 | | | |
| 20 | f(1)_f3_f1 | f(1)_f3_f2 | f(1)_s2_s1 | | | | | |
| 21 | f(1+1)_ch1_g1 | f(1+1)_ch1_g4 | f(1+1)_ch1_g1 | f(1+1)_ch1_g5 | | | | |
| 22 | f(1+1)_ch1_f1 | f(1+1)_ch1_f2 | f(1+1)_ch1_f3 | f(1+1)_ch1_f4 | f(1+1)_ch1_f5 | | | |

f(1): 1-th floor ch: Coffee-table module
c: column g: girder f: floor s: stairs

5. SUMMARY

The prototype system of the virtual construction field where the production situation of the construction site had been paid attention was made. It has been understood that the virtual construction field can effectively support making the production plan by the case study. It will be a problem to make the design specification of the virtual construction field at the practical level.

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