Process optimization for post disaster reconstruction project based on industrial design structure matrix (DSM)

Hui Tang¹ · Qingping Zhong¹ · Chuan Chen²

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Abstract
Post-disaster reconstruction projects face tighter time constraints and are in a more complex environment, making the implementation process of conventional projects unable to meet new requirements. This study decomposes the construction process and then determines the feed-forward and feedback relationship between activities in the post-disaster reconstruction environment. An information relationship diagram is established, and the relationship is transformed into a design structure matrix (DSM). Through DSM manipulation, a partitioned DSM is formed to express the activity process that is more suitable for reconstruction. This research shows that the activities sequence and content need to be changed to adapt to the reconstruction scenario, and some activities may even be canceled. Some suggestions can help construct the project faster, including closer cooperation between design and construction. The bidding scope includes design and construction and the use of more integrated project delivery methods. Finally, a reconstruction case in China illustrates the operability of analyzing and adjusting the implementation process through this framework.

Keywords Post-disaster reconstruction · Design structure matrix (DSM) · Construction process optimization · Project delivery method · Integration

1 Introduction

In recent years, the frequency of disasters and losses has been increasing. According to CRED, only in 2019, 396 natural disasters were recorded in EM-DAT with 11,755 deaths, 95 million people affected, and 103 billion US$ in economic losses across the world (CRED 2020). Buildings and infrastructure, which are the physical basis of people’s livelihood, are often irreversibly damaged when disasters occur. A building or infrastructure must be appropriately designed and constructed to meet the victims’ cultural, social, and physical requirements and provide a set of safe facilities to protect them from possible environmental hazards.

Reconstruction projects can be defined as modification, functional conversion, or reset of existing facilities (McKim and Mohamed 1998). A post-disaster reconstruction project is still a branch of the construction project in a specific environment, so it still needs to follow the essential requirements and process of construction. However, unlike conventional construction projects, post-disaster reconstruction is always in a dynamic and uncertain environment. A construction project needs to deeply identify the owner’s requirements in advance and establish goals based on these requirements. Among all the reconstruction goals and requirements, time requirement is undoubtedly the most urgent (Norling 2013). Completing the project construction at the fastest speed will help restore the economy and society of the disaster-stricken area to normal. In addition, putting the facilities in the disaster area into use as soon as possible helps test the systemic capabilities of different facilities and improve the ability to withstand future disasters.

Conventional construction projects have a lot of techniques and methods to shorten the project time and have some delivery methods to work together. PMBOK
proposes two time-compression techniques, such as crashing and fast tracking (PMI 2017). The crashing technique needs the additional resources input that limits the use of this method. The fast-tracking technique overlaps some activities that were initially carried out in sequence. In the practice of reconstruction, whether the activities are moved forward or overlapped is more based on the manager’s experience and the influence from external stakeholders rather than structured analysis. The complex situation of the reconstruction leads to changes in the assumptions of the technique’s application, and the conventional technical process needs to be adjusted to suit the new conditions.

Some scholars have put forward suggestions on the post-disaster reconstruction model, such as ‘design and build’ (Jayasuriya and Rameezdeen 2010), ‘CMAR’ (Yin and Zhou 2010) and ‘partnering’ (Zhang et al. 2015). However, these suggestions are more from the perspective of performance evaluation of existing projects rather than from the internal process of the project, which may lead to inappropriate decisions. When managing reconstruction projects, there are some issues that scholars and decision makers should notice:

1. Whether the traditional project implementation process needs to be adjusted to meet the unique requirements of the reconstruction scenario?
2. How to change the process without going against the basic logic of construction?
3. After changing the activities in the process, how to carry out effective management?

This article attempts to optimize the current process of the reconstruction project in the post-disaster context, establish a visual project process model to shorten the project time, and find the most suitable reconstruction delivery method to aid. The model is based on the traditional construction process and analyzes the interdependence between activities in a reconstruction environment. Using the DSM method to rearrange the activity process highlights the activities with iteration and coupling relationship and provides help for adjusting the organization of activities and finally achieves the optimized process.

2 Literature review

2.1 Disaster management

Traditionally, disaster management is generally considered a spiraling cyclical process (Alexander 2018), from pre-disaster preparation to emergency response and then reconstruct various facilities in the disaster-stricken area to finally achieve a higher degree of disaster preparedness. Alexander believed that disasters are often recurring events and he considers disaster management a cycle formed by the four stages of mitigation, preparation, response, and recovery (Alexander 2018). In recent years, the concept of resilience has been introduced and integrated into disaster management theory and has become a positive measure for disaster management (Manyena 2006). When it comes to the construction field, a series of changes need to be made from materials, design, internal (components), and external (stakeholders or public) of the project (MacAskill and Guthrie 2015). The project organization needs to establish a comprehensive plan and rapid decision-making mechanism, use appropriate technology to mitigate the crisis and quickly return to normal through mechanisms such as information sharing and resource allocation agreements (Labaka et al. 2016).

Among the four stages of disaster management, the recovery stage usually occurs after the disaster relief stage, ranging from three months to five years, or even longer (Gunawardena et al. 2014). Generally, the recovery includes psychological recovery and socio-economic recovery. The reconstruction of housing and infrastructure systems with appropriate advanced functions and reliable quality is the physical basis for social services and economic recovery. At the same time, the restoration goals of economic and social services have guided the upgrading of the functions and construction methods of housing and infrastructure.

2.2 The process of post-disaster reconstruction

Reconstruction can be defined as ‘the expansions, additions, interior renovation, or upgrading the functional performance, conversion or phased complete replacement of an existing facility’ (Attalla et al. 2004). Most of the existing researches on post-disaster reconstruction projects view the ‘complete replacement’ as the valuable subject and focus on funding (Freeman 2004), reconstruction idea (Saya et al. 2017), successful factors (Ophiyandri et al. 2013), community participation (Sadiqi et al. 2011), and availability and effective management of resources (Chang et al. 2012). These studies are less concerned about the project’s implementation process, so it is not easy to guide the behavior of managers.

Post-disaster reconstruction projects should be regarded as special projects and implemented according to the guidance of project management knowledge (Hidayat and Egbu 2010). Silva believed that the reconstruction project still needs to include three stages: planning, design, and construction (Silva 2010). Scholars and practitioners have identified many goals and challenges for post-disaster reconstruction, such as deliver on time, within budget,
higher quality standards, and multiple participants (Aliakbarlou et al. 2018; Ismail et al. 2014; Francis et al. 2018).

Although post-disaster reconstruction might be a relatively long process (more than twelve months) compared with disaster response, it still needs to make rapid progress. Many scholars agree that time has a positive effect on reconstruction projects. Still, only a few studies have focused on adjusting the construction process to achieve the goal of shortening the construction period (Norling 2013). Fatazi&Arefian revealed the causes and effects of four different segmentations on the time compression of the reconstruction project (Fayazi et al. 2017). Olshansky&Hopkins argued the time compression could improve the design of planning processes and structure of institutions following disasters (Olshansky et al. 2013).

PMI (2017) proposed crashing and fast-tracking techniques to shorten the project time, which has become the starting point of many studies. The traditional CPM scheduling optimization is mainly based on the crashing technique, including working overtime, inputting additional resources, or paying to speed up activities on the critical path.

The fast-tracking technique overlaps part or all of the activities or stages usually completed sequentially (PMI 2017). For example, the foundation of the building is constructed before all architectural drawings are complete. Researchers value this method more because it breaks through resource constraints and emphasizes optimizing the management process (Lee et al. 2006). The time reduced caused by overlapping activities depends on two aspects: the reduced time of overlapping activities and the increased time of rework caused by insufficient information (Bogus et al. 2005).

When activities overlap, specific project delivery methods are required to cooperate. DBB, DB (and similar EPC), and CMR are currently the three most mainstream delivery methods in the industry (Molenaar and Franz 2018), which affect the project’s delivery time by varying the number of contractors, responsibility distribution, and process.

In DBB, the owner signs contracts with three entities in the order of design, bidding and building. Limited by contract authorization, it is difficult for authorized entities to participate in the activities of other entities. When the entrusted entity has any information to transmit, it needs to be transferred through the owner.

The owner signs a DB general contractor contract with an entity, which is responsible for the specific work of design and construction, and all issues within the authorized scope are completed by the general contractor. The designer/builder controls the details of the design and can integrate the construction and design into a whole rather than a piecemeal work (Touran et al. 2011).

CMR also has a general contractor, but during project design, the CMR manager acts as the owner’s consultant. The CMR manager is also responsible for monitoring and controlling the construction process in terms of cost, time, and other requirements. Like DBB, the owner signs a contract with two parties (the designer and the CMR manager).

2.3 The design structure matrix (DSM) method

The design structure matrix (DSM), also called the dependency structure matrix, has become a widely used modeling tool in many areas such as product development and system design (Forbes et al. 2003). In project management, DSM can be used to express and analyze activity dependencies (Eppinger and Browning 2012). The project schedule results from the superposition of the activities sequence and the feedback to a certain extent. Traditional CPM and PERT tools can no longer handle much activity information feedback and iterative loops of complex projects (Eppinger and Salminen 2001). DSM overcomes these shortcomings and is used to improve project schedule performance (Gunawan and Ahsan 2010).

The DSM is a graphical modeling tool used to represent a system’s elements and their interactions (Browning 2016). The DSM can be four categories: component-based DSM, team-based DSM, activity-based DSM, and parameter-based DSM (Yassine 2004). The activity-based DSM is usually used in project scheduling, activity sequencing, and cycle time reduction (Eppinger and Browning 2012). The DSM approach allows the project or engineering manager to represent meaningful task relationships to determine a sensible sequence for the modeled activities (Yassine and Braha 2003). The DSM has been identified as a potential tool to model interdependent activities (or loops), to identify suitable assumptions, formulate, and evaluate the resulting sequence (Maheswari and Varghese 2005). The DSM types and analysis methods are shown in Table 1.

The basic representation of task DSM is an N-square matrix containing a list of activities in the rows and columns in the same order. The order of activities in the rows or columns indicates the execution sequence. The marks represent the information flow between activities. The relationships among the activities are represented with the help of ‘X’ marks in the off-diagonal cells. An ’X’ mark above the diagonal indicates that an assumption of information is required to start the activity. The DSM is particularly well suited to model the sequential and iterative informational relationships between activities in a product development process (Sullivan 2010).

There are three possible relationship types between activities, so there are three corresponding DSM
representation patterns, as is shown in Fig. 1. When feedforward information flows from A to B, place the mark at the intersection of column A and row B of the lower triangle. Conversely, when feedback information flows from B to A, the mark is placed at the intersection of row A and column B of the upper triangle. When there is no information flow between A and B, the corresponding position is empty.

Partitioning eliminate or reduce feedback marks so that dependencies are either below or close to diagonals (Steward 1981). When this is done, we can see which activities are sequential, which ones can be done in parallel, and which ones are coupled or iterative (Yassine 2004). Tearling choose the set of feedback marks to remove from the matrix (and then the matrix is repartitioned), the matrix is repartitioned for determining the preferred execution sequence (Yassine and Braha 2003). Banding is the addition of alternating light and dark bands to a DSM to show independent (i.e., parallel or concurrent) activities (or system elements) (Grose 1994). This article will use the partition to reorganize the activities.

When the matrix is small, partitioning, tearing, banding, and simulation can be implemented using Excel macros. When the system is complicated and for larger problems, this is not feasible, and at some point computer algorithms are absolutely necessary. Genetic algorithm and its evolutionary form have enriched the research field of DSM (Borjesson and Hölttä-Otto 2012; Helmer et al. 2010; Sinha et al. 2020; Borjesson and Sellgren 2013; Sun et al. 2016; Amalia and Dachyar 2018; Zhang et al. 2019).

3 Research methods

It is necessary to adjust the process appropriately to complete the reconstruction project in a shorter time. The reconstruction project should follow the general requirements and procedures of engineering construction. Therefore, this study proposes an improved framework based on the process model of conventional construction projects. First, it analyzes the owner’s demand, construction goal, and activities relationships under the background of reconstruction and then reorganizes activities to find a more suitable construction process for reconstruction. The framework includes four steps:

Fig. 1 Three configurations in DSM analysis

| DSM data types     | Representation | Application                              | Analysis method                                                                 |
|--------------------|----------------|------------------------------------------|---------------------------------------------------------------------------------|
| Activity-based     | Task/activity input-output relationship | Project scheduling, activity sequencing, cycle time reduction | Partitioning, tearing, banding, simulation, and eigenvalue analysis              |
| Parameter-based    | Parameter decision points and necessary precedents | Low-level activity sequencing and process construction | Partitioning, tearing, banding, simulation, and eigenvalue analysis              |
| Team-based         | Multi-team interface characteristics | Organizational design, interface management, team integration | Clustering                                                                      |
| Component-based    | Multi-component relationship | System architecting, engineering and design | Clustering                                                                      |

Table 1 Four different types of data in DSM

| DSM data types     | Representation | Application                              | Analysis method                                                                 |
|--------------------|----------------|------------------------------------------|---------------------------------------------------------------------------------|
| Activity-based     | Task/activity input-output relationship | Project scheduling, activity sequencing, cycle time reduction | Partitioning, tearing, banding, simulation, and eigenvalue analysis              |
| Parameter-based    | Parameter decision points and necessary precedents | Low-level activity sequencing and process construction | Partitioning, tearing, banding, simulation, and eigenvalue analysis              |
| Team-based         | Multi-team interface characteristics | Organizational design, interface management, team integration | Clustering                                                                      |
| Component-based    | Multi-component relationship | System architecting, engineering and design | Clustering                                                                      |
1. Identify the target and determine the scope;
2. Break down project activities;
3. Identify activity relationships;
4. Build and optimize the model.

### 3.1 Identify the target and determine the scope

Establishing the model from the same reality varies under different purposes (Jablonka 2007), so modeling must first identify the target. It is not easy to determine the owner’s goals for post-disaster reconstruction projects because the requests from different stakeholders vary and even conflict with each other. But as mentioned above, time is almost recognized as the highest priority goal of post-disaster reconstruction projects (Alsaadi and Acar 2016). In addition to this, completion within budget is also one of the goals that receive social attention (Adamy and Bakar 2019). However, time, cost, and schedule goals cannot be met at the same time, and other goals will inevitably be damaged under the premise of highlighting one goal.

The main goal of this paper is to shorten the time and develop a method to optimize the reconstruction process. But it should be noted that the method cannot significantly reduce other goals. For example, the method cannot cancel the necessary quality assurance work to shorten the time but can only change the working relationship or merge the related work appropriately. In addition, the internal and external stakeholders are mainly concerned with completing the construction rather than the full life cycle of the project. Although the government’s administrative approval and authorization are related to project implementation, they are also excluded from the study because they are beyond the management scope of contractors and owners. Finally, the scope of research is limited to the period from design to the completion of the project construction by the core organizations. It does not consider maintenance issues after the building is complete.

### 3.2 Break down project activities

The ultimate goal of the research is to find an optimized workflow that is more suitable for the reconstruction scenario by analyzing the relationship between project work and make a more appropriate process or delivery method arrangement. The work breakdown structure (WBS) is a powerful structuring tool (Chua and Godinot 2006). The paper uses WBS to decompose the project construction process to establish the activities relationships. As mentioned previously, the management of a reconstruction project is a specific expression of project management knowledge in the reconstruction environment and not be wholly separated from the project construction process. Therefore, this research applies the general project implementation process to specific reconstruction scenarios and optimizes the process through the calculation to find a delivery method that can quickly complete the reconstruction project. The regular work breakdown of the reconstruction project is shown in Fig. 2. The work is broken down into the same or similar work, which can be completed by a professional team.

### 3.3 Identify activity relationships

In order to reflect a more comprehensive content, the activity relationship does not use the time series connection, but the information relationship. The information of the activity includes the start and finish time, the amount and specifications of resources, the amount and qualifications of personnel, and the limitations of methods and processes. The restrictions on the time are weaker than other restrictions. For example, the latter of activities is often non-main activities such as inspection and clean-up. As long as the resources, personnel, and technology required for the follow-up activities are sufficient, the two can achieve a certain degree of overlap. Therefore, even events with a large time interval may be rearranged together and may be arranged more optimally.

The study acquires the relationship through two aspects. One is the internal process requirements of regular project implementation activities. For example, construction activities need to receive design information before they can start. There is no information exchange between preparing and implementing procurement and providing construction sites. However, the project manager needs to adjust the process due to tighter time requirements, changes in the owner’s functional requirements, and the dynamic nature of the reconstruction environment.

Therefore, the other way is the questionnaire survey of reconstruction project practitioners, some activity relationships in practice are identified. The respondents of the questionnaire included ten project managers who participated in post-disaster reconstruction and three university researchers. Unlike conventional projects, the owner’s demands of reconstruction projects are very vague in the initial stage, and constantly clarified in the design stage or even during construction. The activity relationship is reflected in the feed-forward and feedback information connection between design and daily construction. Another example is that the specifications and models of the materials in the material list guide the implementation of procurement. However, when implementing procurement, procurers may find that the available resources in the market differ from the assumptions and need to be fed back to the material list for modification to continue subsequent construction. The activities relationship is shown in Fig. 3.
3.4 Build and optimize the model

Sequencing the decomposed activities according to the primary order and marking out the feed-forward and feedback information forms an original DSM. The closely related activity blocks highlight using the DSM partition method to create the final optimized DSM. This study uses basic symbolic marks, which only indicate an information relation between the two activities but do not further indicate the strength of the information between the activities. The advantage is to strengthen the decision makers’ understanding of project activities and help make decisions quickly. However, the disadvantage is that it can only reflect whether there is information transmission and the direction of transmission between activities but cannot reflect the closeness of the activities (Yassine and Braha 2003; Browning 2001). It is not worth the time and cost of the decision-makers to collect a large number of actual contact strengths considering the urgency of the post-disaster reconstruction project. At the same time, the uncertainty of the reconstruction environment will weaken the stability of the strength information, so it is acceptable to use only marks for information. The DSM tool is DSM_Program-V2.1 to handle common DSM operations (partitioning) (https://dsmweb.org/. DSM_Program-V2.1. [cited 2020 10.10]; https://dsmweb.org/excel-macros-for-
4 Discussion

One major challenge for reconstruction is the availability of resources (Chang et al. 2011), which makes it difficult to shorten the construction period by increasing resource input. Large-scale reconstruction has increased the contradiction between resource demand and supply. The demand for resources increased drastically in a short period. At the same time, the collapse of the transportation system has hindered the input of external materials. The production and storage capacity of local resources has also been impaired due to disasters. It is challenging to increase resource input per unit of time and shorten the duration. Therefore, changing the reconstruction project’s process and the delivery method seemed to be a viable option.

1. The design and construction should collaborate more closely under the post-disaster reconstruction environment. To implement the project as soon as possible, the owner must put forward project requirements and formulate a plan in a short time. Insufficiencies such as unclear requirements and fuzzy functions can only be clarified, fed back, and modified during the design process. The same situation also occurs between design and construction. When the construction environment is inconsistent with the design assumptions, the construction entity must feed information back and suspend the construct until it receives new drawings. When these two iterative cycles occur between different entities, long work interruptions will be inevitable.

The partitioned DSM reorganizes all activities without violating the inherent development law of the project and highlights the activities with strong correlation in the form of blocks. The detailed design and construction are partitioned in block three, indicating that the building should be closely coordinated with design and provide constructability suggestions. In practice, the reconstruction site is usually chaotic. The early entry of the construction entity can help expose design defects and adjust early. It can also help the construction group grasp the design intent and arrange resource procurement early. An early cooperative relationship establishes through a unified information sharing platform between different organizations (Oduyemi et al. 2017). Another method is to integrate the process into a single group (Arashpour et al. 2015). Although the optimized DSM cannot wholly eliminate feedback and iteration in terms of process, it can simplify a single entity’s internal loop through the internal management process.

2. The partitioned DSM shows that the process has not fundamentally changed, and it still basically follows the route of identifying the owner’s requirements, designing, and construction. The delivery method is not significant change and is still integrating and optimizing design,

| Element Name                        | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|-------------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| identify requirements               |   A1 | 1  | 1  | 1  | 1  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| survey site information             |   A2 | 2  | 2  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| establish objectives                |   A3 | 3  | 1  | 1  | 3  | 1  | 1  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| establish design parameters         |   A4 | 4  | 1  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| develop preliminary design          |   B1 | 5  | 1  | 1  | 1  | 1  | 3  | 1  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |
| coordinate to find compatibilities  |   B2 | 6  | 1  | 1  | 0  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| evaluate and review design          |   B3 | 7  | 1  | 1  | 1  | 7  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| make detailed design                |   C1 | 8  | 1  | 1  | 1  | 1  | 8  | 1  | 1  |    |    | 1  | 1  | 1  |    |    |    |    |    |    |    |    |
| check compatibilities of detailed design | C2 | 9  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| make resource checklist             |   C3 | 10 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| identify qualified parties          |   D1 | 11 | 1  | 1  | 1  | 1  | 1  | 1  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |
| issue bidding documents             |   E1 | 12 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| review and select contractor        |   E2 | 13 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| sign contract                       |   E3 | 14 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| organize project team               |   E4 | 15 | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |
| make construction plan              |   E5 | 16 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| prepare and implement procurement   |   E6 | 17 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| prepare site                        |   E7 | 18 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| plan the daily work                 |   F1 | 19 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| allocate the resources              |   F2 | 20 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| do the physical work                |   F3 | 21 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| inspect and approve the work        |   F4 | 22 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

Fig. 4 The original DSM for post disaster reconstruction

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bidding, and construction. This is also in line with the researcher’s view that an appropriate mature delivery method rather than an utterly unfamiliar one is more suitable for rebuilding the environment (Myburgh et al. 2008). However, it is necessary to redesign the sequence of activities and establish a new workflow because of strict time constraints and a changeable project environment.

The partitioned blocks show that adjusting the position of specific activities in the process and grouping them into certain blocks for overall processing will produce better results in the reconstruction scenario. One change shown in Fig. 5 is procurement. Traditionally, most resources procurement tasks are implemented by contractors after the design is complete, and contractors can choose suppliers and product brands. Figure 5 shows that when the designer can define the material parameters, the material procurement will be carried out without waiting for the bidding to select the contractor to compress time. Another change is that the construction plan is prepared in advance before the project team forms. Under the traditional delivery method, this adjustment is unreasonable. However, block 3 in partitioned DSM shows the feasibility of the early intervention in construction. Due to the changing environment of reconstruction and increasing uncertainty, construction personnel requires to intervene in the design early to increase the constructability of the design and reduce the probability of subsequent rework.

3. Bidding is still a necessary process, but the content and scope need to be adjusted. The development of the design, bidding, and construction of the project has proved its rationality and necessity. Although the reconstruction requires a faster construction speed, the complete process and threshold setting are positively helpful for selecting qualified contractors and ensuring the performance of the project. Choosing reconstruction contractor faces a dilemma. The suddenness and contingency of disasters make it difficult to achieve long-term and stable strategic cooperation. While, post-disaster reconstruction and the changing environment need to ensure the capabilities and qualifications of contractors.

Compared with traditional projects, the reconstruction context has generated more information exchange between design and construction. The review and selection of contractors for conventional projects shall be carried out after the qualified contractors are determined and the bidding documents are issued. However, the partition DSM indicates that it should take precedence over these two tasks. This means that owners should prepare a list of potential qualified contractors in advance instead of selecting contractors through bidding after the disaster. Furthermore, when the contractor was evaluated and selected ahead, confirming qualified contractors and the issuing bidding documents can be cancelled. In addition, although the bidding in DSM is still between detailed
design and construction, it is better to be completed by one entity than to be completed separately because they are divided into one block. Therefore, it is also possible to cancel the bidding and selection of construction units. In this case, even if the owner needs to bid, the overall bidding effect of design and construction is better than construction bidding.

4. The reconstruction needs a more integrated process or delivery method to achieve the goal. The construction industry has always been regarded as fragmented (Fellows and Liu 2012). Design, bidding, and construction are implemented and managed by professional entities, respectively, and there is a lack of practical cooperation among them. The traditional DBB method is low in integration (Asmar et al. 2013), and the owner signs contracts with all parties separately. Any new information beyond the original plan must be sent, received, processed, and finally returned through the intermediary of the owner. If the new data cannot be verified on-site, the cycle mentioned previously will repeat until the construction requirements are met. Therefore, the project time constantly delays in this information cycle.

Partitioned DSM shows the overlap between blocks, activities of different stages are rearranged in one block, and there may be multiple professional works in the block. It indicates that different professional work should be integrated to improve project performance. Although the integration requires higher professionals’ capability, the information exchange of activities within a block is completed by themselves, and thus the path of information transmission can reduce. Considering the significant changes in the reconstruction environment, the tight time, and the requirements of future economic development in the affected areas, the owner should pay more attention to the early planning, clarify the needs and project boundaries (Silva 2010), and reduce the intervention in project implementation by reducing the number of contracts. Delivery methods such as EPC and DB reduce the number of contracts (Gransberg et al. 2006), and the information cycle between designer and builder becomes the internal work of contractors. Therefore, EPC and DB are better than DBB in terms of integration, so they become the more appropriate options for the reconstruction project.

5 Empirical case

5.1 Introduction of the case

On August 8, 2017, a magnitude 7.0 earthquake occurred in Jiuzhaigou County, Sichuan Province in China, causing a total of 8 counties in Sichuan Province and Gansu Province to be affected. The earthquake caused 8.043 billion yuan (1.245 billion US$) direct economic loss and 20.85 billion yuan (3.228 billion US$) indirect economic loss. The infrastructures such as transportation, communications, municipal administration, and public services were severely damaged. After the rescue and disaster relief, the reconstruction work started immediately. On November 6, 2017, the Sichuan Provincial Government put forward the earthquake recovery and reconstruction plan and listed the gymnasium in the project package. The total investment of the gymnasium is 70.8 million yuan (10.96 million US$). In December 2017, the owner determined the project site and commissioned a survey and preliminary design immediately. The initial survey and preliminary design were completed in January 2018. On January 16, 2018, the project was publicly bid. The owner determined the winning bidder on February 14, 2018, and the construction began in March 2018. Finally, the project was delivered on August 13, 2019.

When optimizing the case process, the owner basically followed the route described above, but did not strictly implement it in stages.

5.2 The implementation processes

Since the project was confirmed in November 2017, the owner has faced requirements from the government and the community, including:

1. The project must be completed and delivered before August 17, 2019, to host the planned sports meeting.
2. The functions provided by the project should be popular rather than professional to increase the degree of sports participation in the region.
3. The local government hopes to promote the local urbanization process and increase local employment through this reconstruction project.

Also, the owner has neither practical experience in managing construction projects nor the ability to produce and supply raw materials. At the same time, the owner hopes to explore a completely market-oriented and sustainable reconstruction routine with less government intervention.

The owner estimated that the project’s total time would be as long as 775 days if the traditional method was used, and the expected completion time would exceed November 2019. Figure 6a shows the shortest total time estimated following conventional construction methods, in which the values of each stage are derived from the survey of projects of similar type and scale, the minimum time requirements in legal provisions, and the duration norm issued by the Ministry of Housing and Urban–Rural Development of the People’s Republic of China. These methods and data are
also used to estimate the progress of conventional projects in China.

To reduce the total period, the owner analyzed each stage’s functional relationship and role and decided to change the work process and delivery method. Figure 6b shows the whole duration after adjusting the workflow. After analysis, the owner decided to take some measures:

1. Rearrange the survey and the design. One month after releasing the plan, the owner determined the site on December 7, 2017, and commissioned the company to conduct a site geological survey in December 2017. After analyzing the functions of the site survey, the owner divides the site geological survey into two parts: preliminary survey and detailed survey. The initial survey was placed after choosing the site and before designing the preliminary to provide parameters for preliminary structural analysis. The detailed survey is carried out simultaneously with the preliminary design, and the result is not only used as the input condition of the detailed design but also fed back to the preliminary design for correction.

2. Integrate the requirement identification with design. The owner believed that it is difficult to express the requirements accurately, and it takes more time to entrust a consultant to identify the needs and the feasibility study. Therefore, the owner merged the identification requirements into the preliminary design. When entrusting the initial design, the owner only put forward basic needs. The needs include the gymnasium seats reach 3000 (including 2200 fixed and 800 active seats) for future operation, one formal basketball court on the ground and two training courts underground, all courts need be easily converted into badminton, table tennis, and gymnastics. In communicating, the design drawings are iterated and revised constantly, and the owner’s needs and goals gradually become clear. Finally, the preliminary design clarified the site geological conditions, functional requirements, total floor area and layout, personnel flow organization, structural design level, structural type, water supply power, electrical equipment power, and other professional basic requirements and parameters. These requirements are written into the bidding documents and become the contractor’s work objectives and constraints.

3. Expanding the bidding content to design, procurement and construction. On January 16, 2018, the owner published the tender notice on the public website. The bidding is a statutory procedure in China, which cannot be canceled or simplified. The owner expanded the work content and entrusted the contractor to complete the detailed design, material procurement, and construction. This method is less applied in post-disaster reconstruction in China, and experience accumulation is less. To reduce the probability of project failure, the owner evaluated the difficulty of project implementation and the number of capable contractors during the
preliminary design, allowing contractors to participate in bidding as a single entity or joint venture, but must undertake detailed design, material procurement, and construction. As the contractor was evaluated in advance, the contract signing time was shortened by about 15 days.

In the end, a joint venture formed by a design company and a construction company won the bid and became the EPC general contractor to conduct the design, procurement and construction. After an in-depth analysis of the bidding documents and preliminary design documents, the general contractor believes that some issues may reduce the performance of the schedule and need to strengthen management. (1) The process and efficiency of information transmission between the designer and the construction staff; (2) the matching of design documents and construction; (3) the needs of the owner are easy to change. The general contractor took some corresponding measures, mainly including:

A. In response to problems such as deviations in understanding design documents by construction personnel and extended information transmission paths, the two companies sent personnel with similar project experience to set up a project management office on site. In the design process, the designer and the construction staff discussed the design details together. They strived to reduce misunderstandings and errors in the construction—the construction staff also timely feedback the deviation on-site to the designer for correction.

B. The general contractor allowed and encouraged construction personnel to put forward constructability suggestions during the design process to reduce items of difficulty to realize in the design drawings. Through this measure, construction feedback was shortened or eliminated, and rework and demolition caused by this were reduced.

C. The general contractor studied the bidding documents and discussed with the owner and the designer and believed that there were uncertainties in the details of the requirements and the choice of the project implementation plan by the owner, which may cause demand change during implementation. Therefore, the general contractor strengthened the active communication between the designer, construction staff, and the owner and explained similar projects to the owner to help the owner make an early decision. Detailed design and construction are reduced by 85 days in total.

Figure 6 shows the estimated time for the initial plan and the actual time after the adjustment process. The comparison shows that using the proposed analysis framework to optimize the process reduced the total project duration by about 17%. However, there are still shortcomings. The analysis is not detailed enough because it is the first time this framework tool has been used in a reconstruction project. The analysis only involves the main stage and fails to go into each stage’s specific work or work package. Therefore, it was unable to optimize the work in-depth and to analyze the shortened time’s performance from a quantitative perspective, such as the proportion of eliminating rework in the reduced time.

It should be noted that the shortening of the project duration does not only rely on the adjustment of the relationship between the process and the activities. In fact, the shortening of the construction period is a comprehensive result of many factors. The case project has adopted many technical measures, such as the use of more efficient equipment, but these technical measures need to be combined with process reengineering or subject to process. Therefore, this study did not consider these reasons separately.

6 Conclusion and future research

Reconstruction is an urgent issue after the disaster. After small disasters, reconstruction is not much different from conventional projects and can be implemented following the construction process and requirements of ordinary projects. However, reconstruction projects face more complex situations after massive disasters or catastrophes, and the relationship between activities needs to be further optimized to meet delivery time and speed requirements. Many conventional project management methods need to be innovated to adapt to the new characteristics of the reconstruction project, including schedule control tools, cost estimation, and delivery methods. The mutual constraints of the overall restoration goals and the environmental chaos largely limited the owner’s determination and construction scope.

There are many routes and methods to shorten the time of construction projects under reconstruction circumstances, and it is difficult to shorten the project time by increasing resources. The more suitable option is to adjust the relationship between activities and change the delivery method to achieve time compression. In this paper, the relationship between activities of the reconstruction project is analyzed, and DSM establishes the model of activities in different stages of the reconstruction project. The partitioned DSM reorganized project activities. Some cross-stage activities have been adjusted closer, and a new relationship with the reconstruction scene has been revealed. The partitioned activity matrix indicates that a more integrated project delivery method such as EPC or
DB should be adopted to meet the needs of the reconstruction situation.

This research shows that the DSM method can play a positive role in the process optimization of reconstruction projects. The scale and complexity of the cases are not extreme and special projects, so excel macro-processing can be used. When optimizing more complex or higher-level optimizing requirements, such as project groups (programs) that compete with each other for resources, we can use the same principles to develop targeted DSM algorithms.

The limitations and direction of this research involve the in-depth use of DSM. The strength of the activity relationship can more closely describe the costs and benefits of activity adjustment, and the team relationship can help organize professionals. Future research should integrate DSM more deeply to improve decision-making efficiency. Another direction is to embed DSM into Alliancing and IPD, which could drastically change project management.

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest All the authors declare that they have no conflict of interest.

Informed consent All authors agree to submit this edition and declare that no part of this manuscript has been published or submitted elsewhere. We thank you for your consideration of our manuscript and look forward to receiving comments from the reviewers as soon as possible.

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