An activity-based lessons learned model to support scheduling decisions in construction

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AN ACTIVITY-BASED LESSONS LEARNED MODEL TO SUPPORT SCHEDULING DECISIONS IN CONSTRUCTION

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ABSTRACT

Purpose: The aim of this study is to develop an activity-based lessons-learned model that allows construction companies to capture, store, classify, and reuse activity-related lessons learned from previous projects, thereby increasing the reliability of time estimates in scheduling.

Design/methodology/approach: Scheduling is a knowledge-intensive process that requires the utilization of data and expert opinion elicitation from various levels of an organization in construction projects. This research consists of five successive steps: performing a needs analysis, proposing an activity-based lessons-learned process model, validating the proposed process model, developing a tool to apply the proposed model in a computer environment, and testing the applicability of the tool. To implement the proposed model in practice, a web-based tool, namely the Construction Industry Scheduling with Activity-Based Lessons Learned Tool (ConSALL Tool), was developed. Its functionality was evaluated using black-box testing. The tool was then applied in a real construction project.

Findings: Results show that ConSALL has the potential to improve scheduling decisions in construction projects by incorporating data and experience from previous projects. Findings

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from this research can be used to develop similar models and AI tools to foster activity-based learning in other project-based industries as well as the construction industry.

Originality: This paper presents an innovative approach to enhancing construction project scheduling by leveraging lessons learned from past projects. The development and application of the ConSALL Tool demonstrate a practical implementation of the proposed model, providing a framework that can be adapted to other industries to improve project planning and execution.

Keywords: construction project, knowledge management, lessons learned, scheduling, web-based tool.

1. Introduction

Construction industry is one of the largest contributors to global economic growth accounting for 13% of GDP (Johnson and Babu, 2020). The global construction industry generates a turnover of approximately USD 7 trillion and employs nearly 120 million people (CICA, 2023). Despite significant growth in the number of construction projects each year, it is argued that the industry has not yet reached the desired level of success in project implementation (Shirazi and Toosi, 2023). Although meeting project deadlines is a key success criterion for construction projects (Arantes and Ferreira, 2021; Hansen et al., 2023), previous studies show that the vast majority of construction projects, whether small or large scale, are not delivered within their original schedules (Yap et al., 2021; Alashwal and Alashwal, 2022; Sambasivan and Soon, 2007; Wang et al., 2022). Gurgun et al. (2022) found that more than 85% of large-scale projects worldwide are not completed within their planned schedules, while Flyvbjerg (2014) reported that 90% of megaprojects experience time overruns. These delays are primarily caused by poor project planning and scheduling (Mohammadi et al., 2022). Similarly, Yap et al. (2022) found that, out of 30 factors that may cause delay in construction projects, improper planning and scheduling stands out as the dominant reason of delay. The knowledge-intensive nature of the scheduling process makes it vulnerable to risk of inadequate/lack of information, which is commonly experienced in construction projects. Within this context, information gathering and utilization becomes a critical success factor for scheduling and minimization of delay.

Recognizing the importance of knowledge in the success of companies in today's competitive business environment, companies conceive knowledge management as a critical task that can give them a competitive advantage (Kivrak et al., 2008 ; Eltigani et al., 2020). Knowledge management is vital for improving the business performance of companies, especially in project-based industries (Tserng and Lin, 2004). The construction industry is one of the project-based industries that has the potential to benefit from knowledge management, as it produces a massive amount of experience-based knowledge throughout the lifecycle of a project. The lessons learned process, which is an essential part of knowledge management, is a typical way to eliminate challenges, identify innovations and advancements in project-based industries (Carillo et al., 2013). Although many researchers have emphasized the importance of lessons learned in the construction industry, construction companies still face difficulties in using their accumulated knowledge in future projects due to a lack of effective knowledge management strategies and tools. In this study, our aim is to develop a lessons-learned process model and tool that allow construction companies to analyze past project data, identify recurring patterns or trends that be used to improve scheduling performance in forthcoming projects. Although several project-based learning tools have been developed in the literature as will be explained in the Literature Review section, our study is different than these tools as it is specifically developed for scheduling thus it is activity-based. Construction companies can enhance the reliability of time estimates and reduce time overruns in construction projects by effectively capturing, storing, and reusing activity-related lessons learned. Hence, the objective of this study is to develop an activity-based lessons-learned process model for scheduling (ALLPMS) and a web-based tool to capture, disseminate, and reuse lessons-learned knowledge based on this model which will be explained in the forthcoming sections.

2. Literature Review on Managing Knowledge and Lessons Learned Process

According to Chaffey and Wood (2005), “Knowledge is the combination of data and information, to which is added expert opinion, skills, and experience, to result in a valuable asset which can be used to aid decision making”. There are two types of knowledge, namely tacit and explicit. Explicit or codified knowledge can be expressed as a corporate asset that is either documented on paper or preserved electronically on computers (Ozorhon et al., 2005). Reports, articles, contracts, e-mails between different parties, specifications, design codes, textbooks, and visual documents like photos can be categorized as explicit knowledge in organizations (Lin et al. 2006; Kivrak et al., 2008). On the other hand, tacit knowledge is “a complex context-dependent notion which covers a wider range of diverse cases with examples of it including intuition and interpersonal skills” (Addis, 2016). While it is easy to reach explicit knowledge, tacit knowledge cannot be accessible unless it is converted into explicit knowledge (Ozorhon et al., 2005). As there is no definite method of automatically extracting tacit knowledge, organizations have applied different approaches to extract the associated knowledge from previous projects.

The knowledge management process can be an efficient way to extract both tacit and explicit knowledge by collecting, storing, and disseminating vital assets in the organization (Haghgooie, 2012; Williams, 2008). Moreover, knowledge management provides significant potential to prevent repetitive mistakes (Anumba et al., 2005). Lessons learned (LL), which can be defined as “key project experiences which have a certain general business relevance for future projects”, are essential parts of knowledge management systems. They are intelligent resources that help to produce value using previous experiences (Carillo et al., 2013). In addition, they are crucial for increasing the productivity of industries (Oti et al., 2018). Many governmental, commercial, and military organizations have implemented lessons-learned systems to share verified experience-based lessons (Weber et al., 2001). Although the usefulness of lessons-learned systems has also been understood by many organizations in the construction industry (Caldas et al., 2009), the lessons-learned from past projects have not been implemented in future projects as extensively as expected (Love et al., 2018). LL practices include people, processes, and tools that enable organizations to acquire, analyze, store, and reuse the information or experiences that add value to organizations (Caldas et al., 2009). Paranagamage et al. (2012) defined the practices for LL in the construction industry as post-project reviews, company intranet-extranet, face-to-face meetings with the project team, telephone conversation, brainstorming, knowledge repositories, minutes of meetings, project files, communication of practices, technical forums, and video conferencing.

Several studies have focused on the implementation of LL systems in the construction industry. Kartam and Flood (1997) proposed the "Constructability Lessons Learned Database (CLLD)" prototype that can automatically collect, systematically organize, and use important construction information for contractor's daily activities. Saad and Hancher (1998) developed a lessons-learned tool to track the progress of construction projects and document the lessons from the projects. Soibelman et al. (2003) developed a lessons-learned system, called Corporate Lessons Learned, to capture, and reuse the personal experiences and lessons learned on construction projects. The proposed system particularly focused on the design review process of the construction projects. Tan et al. (2007) offered a web-based system to capture and reuse project knowledge in all phases of construction projects. Kivrak et al. (2008) created a conceptual framework for acquiring, storing, and sharing both tacit and explicit knowledge in construction projects. They developed a web-based system, namely Knowledge Platform for Contractors (KPfC), to demonstrate the applicability of the proposed model. Arditi et al. (2010) developed a lessons-learned system, namely CMAID- A lessons learned system in construction management practices, to accumulate, classify, store, access, retrieve, and disseminate lessons learned for management practices in a construction project. In this context, 12 main categories, and 5 hierarchical levels of subcategories were created to categorize the construction management practices into the database. Goodrum et al. (2003) offered a lessons-learned system to gather the lessons for all phases of transportation projects. Ferrada et al. (2016) developed a mobile cloud-share workspace to enhance LL systems in the construction industry. Oti et al. (2018) built a model that integrates the LL information in BIM. The integration was performed by adding the nonstructured query system in a BIM-enabled environment. The proposed system can store and access the LL information using the BIM environment. Kim and Chi (2019) created a construction accident knowledge system that automatically retrieves tacit knowledge by analyzing accident reports. Eken et al. (2020) proposed a lessons-learned management process for capturing and transferring knowledge across different projects. They also developed a web-based IT tool (LinCTool) to actualize the proposed model.

Table 1. Summary of Literature Review

Study	Proposed System	System Domain	Platform
Kartam and Flood (1997)	Constructability Lessons Learned Database (CLLD)	Constructability	Microsoft Lotus
Saad and Hancher (1998)	Project Navigator	All phases of construction projects	Standalone desktop tool
Soibelman et al. (2003)	Design Review Checking System (DrChecks)/Corporate Lessons Learned (CLL)	Design Review Process	Web-based
Goodrum et al. (2003)	KyTC Lessons Learned System	All phases of transportation projects	Web-based
Tan et al. (2007)	Capture and Reuse of Project Knowledge in Construction (CAPRIKON)	All phases of construction projects	Web-based
Kivrak et al. (2008)	Knowledge Platform for Contractors (KPfC)	All phases of construction projects	Web-based
Arditi et al. (2010)	CMAID - A lessons learned system in construction management practices	Construction management practices in construction projects	Microsoft Access 2003
Ferrada et al. (2016)	Mobile Cloud Shared Workspace (MCSW)	Construction Project Management Process	A mobile platform
Oti et al. (2018)	A model that integrates the LL information in BIM	Construction Phase	Excel spreadsheet and Navisworks
Kim and Chi (2019)	Construction accident case knowledge management system	Construction Accident Cases	Online platform
Eken et al. (2020)	Lessons learned management process model (LLMPM)	All phases of construction projects	Web-based

Table 1 summarizes the lessons-learned systems developed in the past decade for use in the construction industry. This table outlines the domain in which each system is applicable, such as design review, construction accidents, and constructability, along with their key characteristics. A review of the literature indicates that many studies have implemented lessons-learned systems to capture and reuse the lessons for various purposes. However, there have not been any previous studies reported in the literature that particularly focused on integrating the lessons-learned process into project scheduling. Construction scheduling is a critical component of successful construction projects and relies heavily on knowledge gained from past experiences (Mohammadi et al., 2022). Related information from past schedules can significantly assist construction schedulers in making their scheduling decisions (Russell et al., 2009). Therefore, the underlying motivation behind this research is developing a method to utilize past experiences and data about project activities which can have a significant impact on the quality of construction scheduling.

In this context, the objective of this study is to develop an activity-based lessons-learned process model that allows construction companies to capture, store, classify, and reuse activity-related lessons learned from previous projects. To implement this model in practice, a web-based tool, namely Construction Industry Scheduling with Activity-Based Lessons Learned Tool – ConSALL Tool, was developed.

The novelty of the study stems from its focus on integrating lessons-learned processes directly into project scheduling via learnings at the activity-level which represents a novel approach that has not been extensively explored in previous literature. By developing an activity-based lessons-learned process model specifically tailored for construction scheduling, this study contributes to advancing knowledge in both project management and construction scheduling methodologies. It offers insights into how lessons learned from past projects can be systematically utilized to enhance scheduling accuracy. Development of the ConSALL web-based tool provides a practical means for implementing the activity-based lessons-learned process model in real-world construction projects.

3. Research Methodology

This research consists of five successive steps as performing need analysis, proposing an activity-based lessons learned process model, validating the proposed process model, developing a tool to apply the proposed model in the computer environment, and testing the applicability of the tool in a real project. The summary of the research methodology is presented in Figure 1. As can be seen from Figure 1, interviews with domain experts have been carried out at 3 different phases of the research study. A total number of 10 construction industry professionals participated in different stages of interviews throughout the study. Although the interviews were conducted in Türkiye, the participants should not be regarded as local experts. These professionals work for global companies and have extensive international experience, having been involved in diverse construction projects across different regions worldwide. Their global experience ensures that the insights they provided are relevant and applicable to a broad range of construction contexts. On average, the selected experts had 12 years of experience in the construction industry, working on a variety of project types, including residential, commercial, and infrastructure projects. The interviews were carried out over a six-month period, from January to June 2021. The profile of the experts who participated in this research study is presented in Table 2.

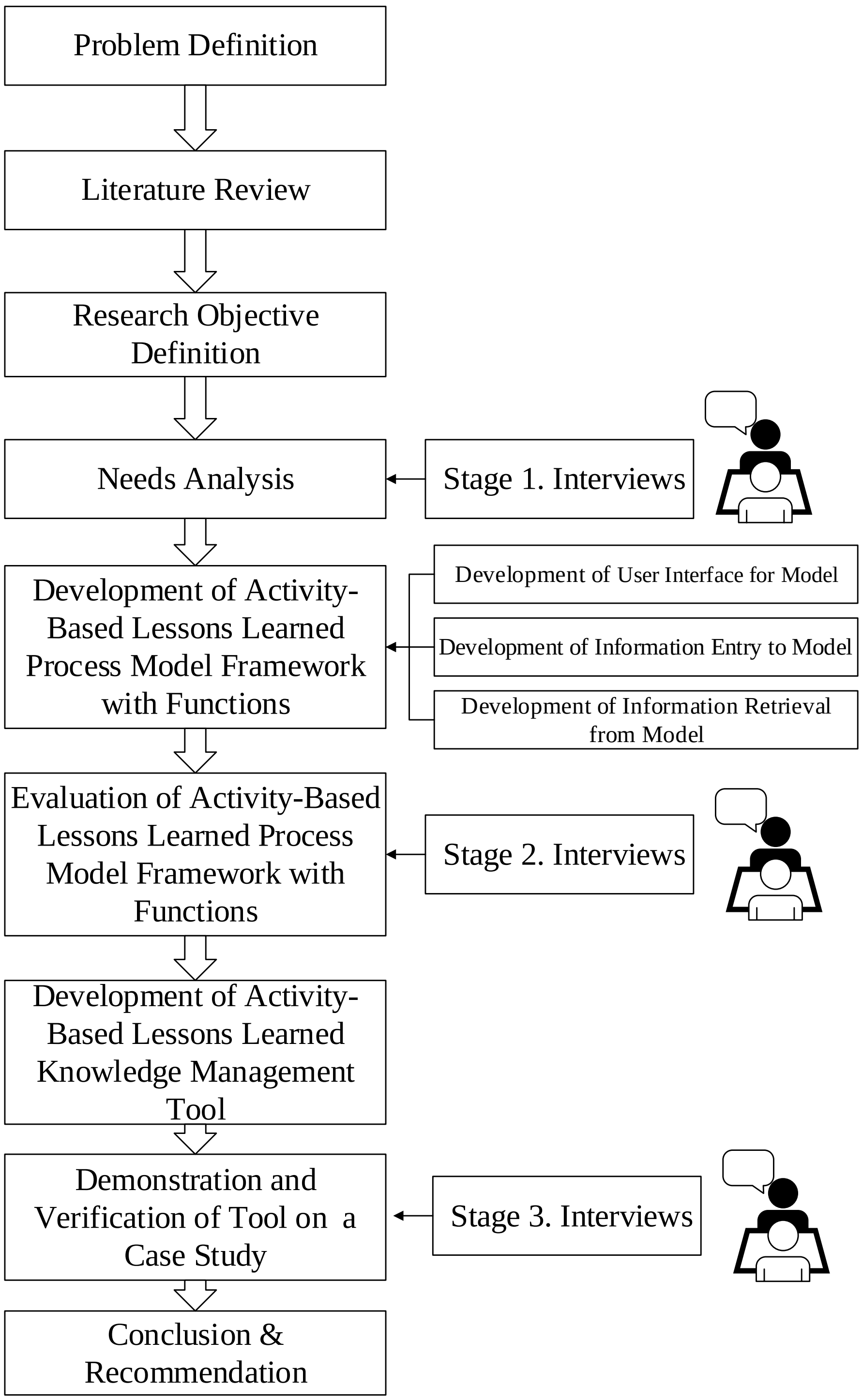

Fig. 1. Research Methodology

Table 2. Profile of the experts that participated in the research study

Respondent	Position	Experience	Stages of interviews participated
Expert 1	Lead Planning and Cost Control Engineer	9 Years	Stage 1, Stage 2, Stage 3
Expert 2	Academician and Planning Expert	10 Years	Stage 1
Expert 3	Lead Tendering and Proposal Engineer	7 Years	Stage 1
Expert 4	Senior Planning and Claims Management Engineer	13 Years	Stage 1
Expert 5	Senior Planning and Cost Control Engineer	18 Years	Stage 1
Expert 6	Lead Planning and Cost Control Engineer	9 Years	Stage 1
Expert 7	Projects Control Director	19 Years	Stage 2
Expert 8	Projects Monitoring and Control Specialist	9 Years	Stage 2
Expert 9	Technical Office Manager	21 Years	Stage 2
Expert 10	Lead Planning Engineer	8 Years	Stage 3

3.1. Need Analysis

The research was initiated by carrying out a need analysis to clarify the features of the activity-based LL system. The needs analysis was conducted through a combination of literature review and semi-structured interviews with industry professionals. In the first stage of this step, an extensive literature review on lessons learned in management and construction scheduling was performed to identify gaps in knowledge management practices. In the next stage, semi-structured interviews (Stage 1. Interviews) were conducted with six construction industry professionals who had experience in construction project management, especially in construction planning and cost control. The questionnaire included three main parts. In the first part, general information about the respondents were requested. In the second part, the scope of the research was presented. In the last part, the expectations and recommendations for the features of the LL system were requested. A face-to-face video call was arranged with each respondent to discuss the feedback in detail.

All experts appreciated the idea of developing an LL system that integrates the previous project knowledge into the scheduling of the new projects. After the in-depth analysis of the literature review and findings from interviews, the critical features and tasks were identified as follows:

1. Developing an activity-based lessons-learned (LL) system that enables capturing, storing, classifying, and reusing the knowledge obtained from previous projects.
2. Identifying the requirements for capturing and storing activity-specific tacit and explicit knowledge.
3. Identifying retrieval mechanisms to share the activity-specific knowledge.
4. Identifying methods to query lessons according to different project attributes.
5. Identifying user roles and their authorization levels to maintain system organization.
6. Developing a construction taxonomy according to the company needs to tag the activity-based lessons that help to query lessons.
7. Identifying the factors and their impact rate that can affect the productivity rate of activities to estimate the similar activity's productivity rate for future projects.
8. Capturing and storing the activity productivity rate (unit per man-hour) information with their affecting factors in a structured way.
9. Identifying a method for calculating the activity productivity rate.
10. Developing user-friendly interfaces to create and display activities and projects easily.

11. Developing user-friendly interfaces to enter and retrieve activity-based lessons learned easily.
12. Developing user-friendly interfaces to retrieve activity-based productivity (unit per man-hour) information with affecting factors.

To sum up, it can be stated that the findings from the need analysis show that the construction industry still lacks an effective LL system to capture and reuse activity-based information. In addition, as mentioned in interviews, activity-based productivity information and causal factors were prominent information sources that should be included in the LL system.

3.2. An Activity-Based Lessons-Learned Process Model for Scheduling

The process model of the activity-based lessons-learned system that was developed based on the defined needs is presented in Figure 2. As the activity information is captured from the related project, the first step is the creation of the project schedule according to the project requirements. After preparing the project schedule, two different types of activity information can be concurrently entered into the system. The first one is the entry of the activity productivity information that shows the actual productivity rate (unit per man-hour) information of an activity, the second one is the entry of an event that affects the activity's planned duration, which is also called as a "proposed lesson". In the next step, the proposed lesson is checked by the authorized person to ensure the quality and reliability of the information. After the necessary revisions (modify, delete, or approve) for the entered lesson are made by the authorized person, the lesson and activity productivity information are ready to be retrieved from the system.

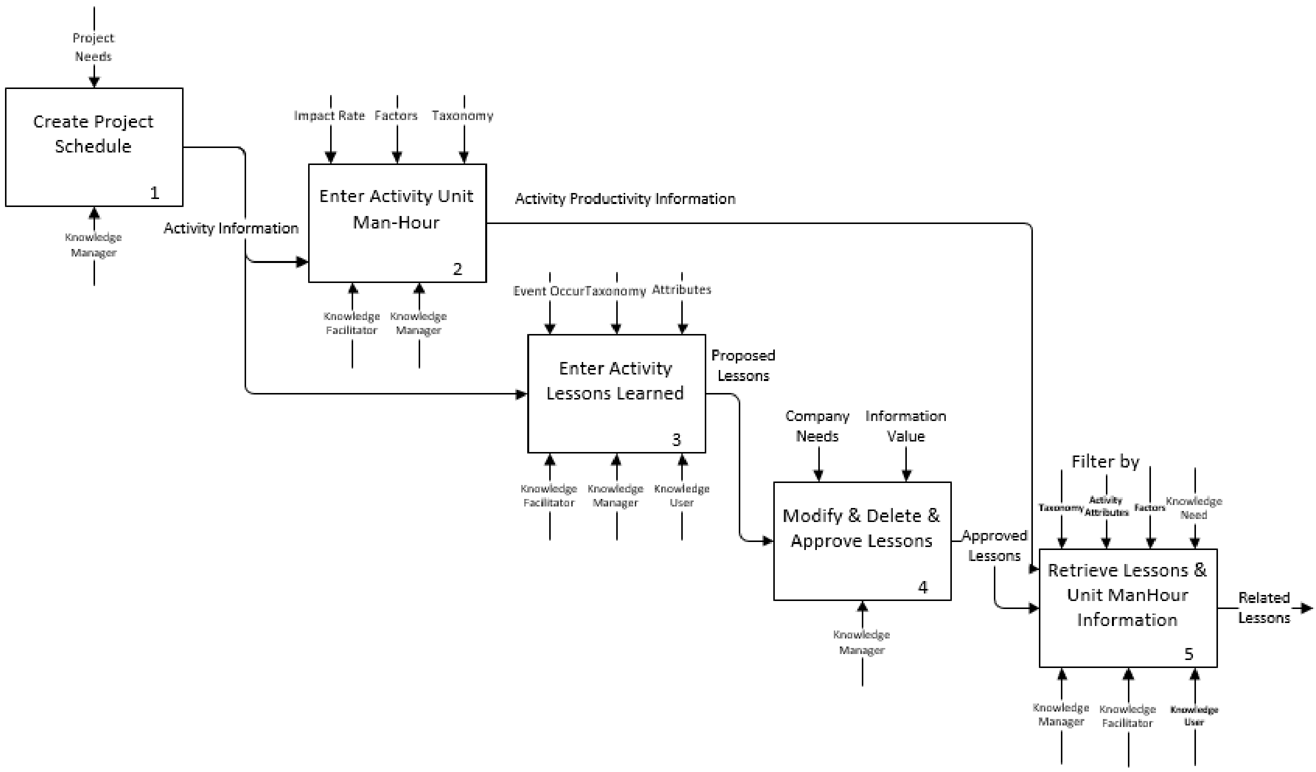

Fig. 2. Process Model

As shown in Figure 2, the process model includes different activities such as entering activity-specific information, editing taxonomy, and deleting-modifying-approving lessons, therefore to increase the efficiency of the system integrity, the responsibilities should be properly identified. Eken et al. (2020) also mentioned that it is crucial to define responsibilities to keep the structure of the proposed model consistent. In the proposed process model, three different roles were defined as “knowledge user”, “knowledge facilitator”, and “knowledge manager”. The responsibility of each role is presented in detail in the use case diagram as shown in Figure 3. Employees, who are qualified enough to enter the new lessons into the system, are identified as **“**knowledge user”. They cannot make any changes to the system, however, they can search and display lessons that have already been added to the database. Employees, who are identified as **“**knowledge facilitator”, are responsible for gathering daily activity information on-site. This information includes the “unit per man-hour” of the activity, “factors” that affect the productivity of the activity, and the “impact rate” of each factor. They are also responsible for entering the on-site collected information into the database. The “Knowledge manager” role was created to review (edit/delete/approve) the lessons that have been already entered into the system by the “knowledge user”. This review process is performed according to the values of the lessons and aims to prevent an overload of information in the system. Once the lesson is entered into the system by the “knowledge user”, the system automatically labels this lesson as unapproved. According to the evaluation of the “knowledge manager”, the lesson is approved, deleted, or approved with some modifications. As the reliability of the system highly depends on the decisions of the “knowledge manager”, the “knowledge manager” should be an experienced professional in the company. “Knowledge manager” is also responsible for creating the project in the system, as well as transferring the project activities and their planned start times, finish times, and durations into the database.

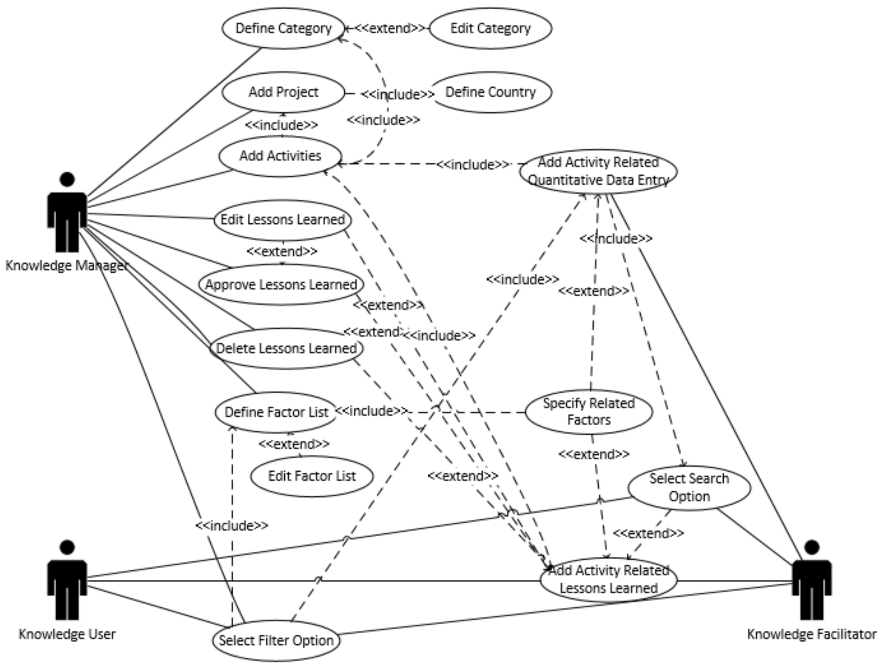

Fig. 3. Use Case Diagram of ALLPS

The system involves two main workflows, namely "recording information into the database" and "using information from the database". A detailed flowchart of the model is presented in Figure 4.

The information recording process starts with controlling the database whether the project is available or not. After, the taxonomy is arranged according to the project needs. Once the project activities are added to the system by the "knowledge manager", the activity-related lessons learned are recorded in the database by the "knowledge user". Activity-related lessons learned are the events or situations that have a direct impact on the activity. They include qualitative (tacit and explicit) lessons learned knowledge. The recorded lessons can only be stored in the system database after the approval of the "knowledge manager". On the other hand, activity productivity information, which is quantitative information about activities, is added to the database by the "knowledge facilitator".

An essential and difficult step in designing a knowledge management system is developing a framework that would enable retrieval of the appropriate lesson (Eken et al., 2020). As shown in Figure 4, the model provides three different search options to retrieve the recorded information from the database. For the first alternative, once the desired activities are selected from the drop-down menu, activity-related quantitative information is filtered by identifying factors affecting the productivity of the activities and their impact rates. In the second alternative, lessons learned are filtered by selecting the desired activity from the drop-down menu. The other option is filtering activities and recorded information by using the project and activity attributes. Further explanation about the information entry process and search options will also be provided under the Tool Section.

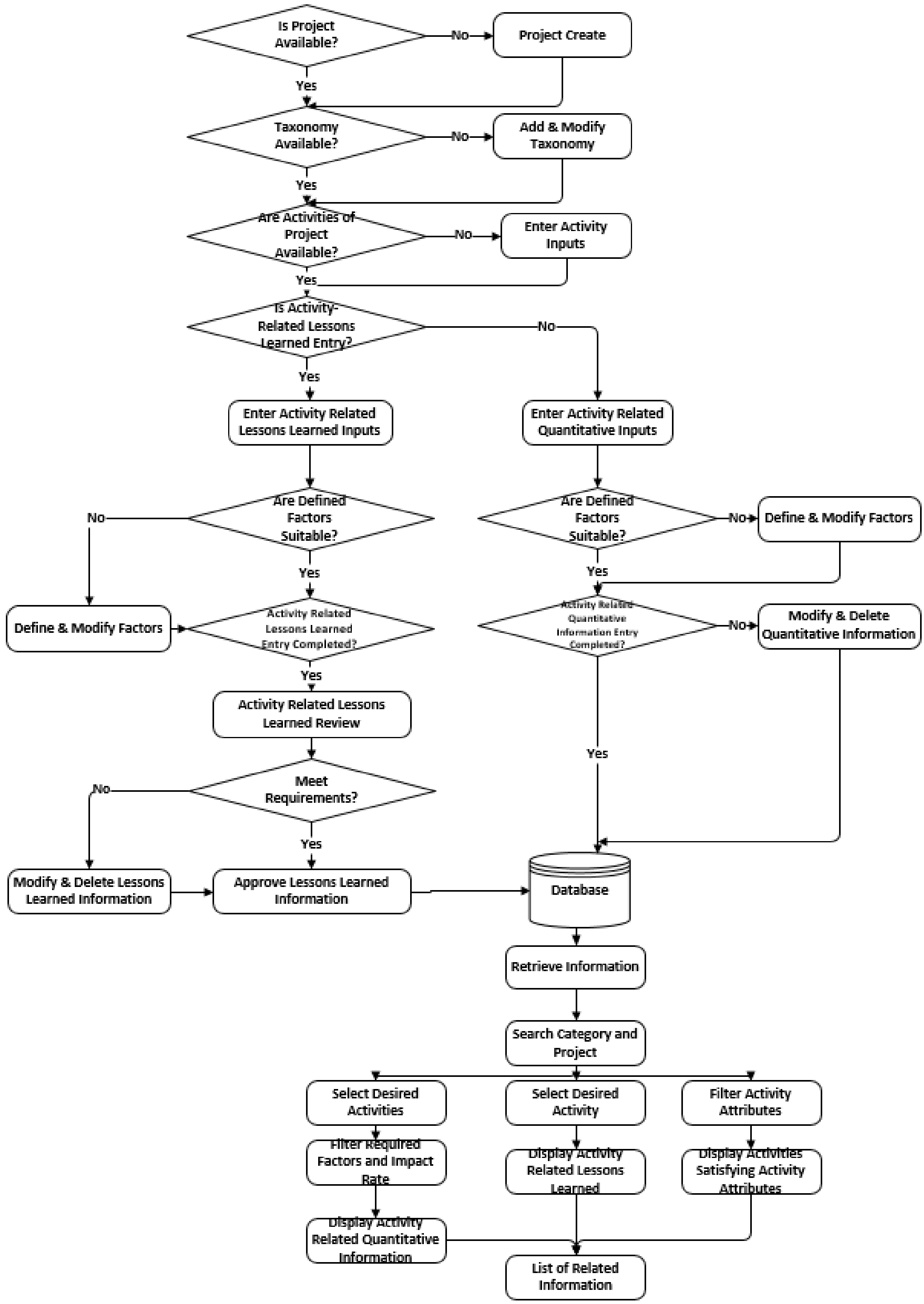

Fig. 4. Flowchart of the Information Entry and Retrieval

3.2.1. Activity Productivity Rate

In construction projects, the decision-makers generally estimate the duration of the projects with the help of their past experiences. These estimations are mainly based on subjective judgments without relying on any numerical data. As found as a result of interviews, it has been aimed to capture and store the activity productivity rate (unit per man-hour) information with their causal factors in a structured way, so that the decision-makers can easily access the related data while estimating the duration of activities. Yi and Chan (2014) defined construction productivity as “a measure of outputs that are obtained by a combination of inputs”. Since the primary resource in the construction industry is manpower (Jarkas, 2010), construction productivity often refers to labor productivity (El-Gohary and Aziz, 2014). Total factor productivity and partial factor productivity are the two common methods that have been used to measure productivity (Thomas and Sudhakumar, 2015). Total factor productivity can be defined as the output per all inputs, on the other hand, partial factor productivity can be regarded as the output per selected inputs (Rathnayake and Middleton, 2023; Yi and Chan, 2014). As the partial factor productivity method is activity-oriented (El-Gohary and Aziz, 2014), it was used in the proposed model to measure the productivity of the activity. In this method, productivity can be calculated by the following equation.

$$\text{Partial Factor Productivity (PFP)} = \text{Output Quantity/Labor Hours} \quad (1)$$

3.2.2. Factors Affecting Activity Productivity Rate

According to the suggestions of interviewees, the factors affecting the productivity rate of the activities were determined by means of an extensive literature review. Table 3 summarizes the factors and their sources. The factors were clustered into three main categories as “general”, “labor-related”, and “machine-related”. The “General” category includes 10 factors, whereas machine-related has 3, and "labor-related" has 4. The factors identified are further used to develop the tool but can be customized according to company needs.

Table 3. Factors Affecting the Productivity of the Activities

Activity-Related Factors		
Factor Code	**Factor Category**	**Source**
General		
G.1.	Weather Condition	Fagbenro et al. (2024); Kim and Jang (2024); Ok and Sinha (2006), Zayed and Halpin (2005), Zayed and Halpin (2004); Choi and Ryu (2015), Woldesenbet (2005), Jiang and Wu (2007), Al-Zwainy (2012), Sanders et al. (1993), Muqeem et al. (2011)
G.2.	Activity Complexity	Palikhe et al. (2019), Choi and Ryu (2015), Woldesenbet (2005), Ashuri et al. (2014)
G.3.	Organizational Complexity	Ashuri et al. (2014), Ok and Sinha (2006), Woldesenbet (2005), Jiang and Wu (2007),
G.4.	Site Condition	Palikhe et al. (2019), Ok and Sinha (2006), Choi and Ryu (2015), Muqeem and Idrus (2011), Al-Zwainy (2012)
G.5.	Location of Project	Alaghbari et al. (2019), Woldesenbet (2005), Jiang and Wu (2007), Muqeem and Idrus (2011), Ashuri et al. (2014)
G.6.	Planning- Schedule Concern	Alaghbari et al. (2019),Zayed and Halpin (2005), Choi and Ryu (2015), Ashuri et al. (2014), Heravi and Eslamdoost (2015)
G.7.	Construction Method	Alaghbari et al. (2019), Zayed and Halpin (2005), Zayed and Halpin (2004), Sanders et al. (1993)
G.8.	Design Quality & Requirements	Alaghbari et al. (2019), Sanders et al. (1993), Ashuri et al. (2014)
G.9.	Site Management (Coordination & Organization & Interoperability)	Palikhe et al. (2019), Alaghbari et al. (2019), Ok and Sinha (2006), Zayed and Halpin (2004), Zayed and Halpin (2005), Ashuri et al. (2014), Offiah (2017), Heravi and Eslamdoost (2015)
G.10.	Material Availability	Alaghbari et al. (2019), Zayed and Halpin (2004), Choi and Ryu (2015), Muqeem et a. (2011), Al-Zwainy (2012)
Machine-related		
M.1.	Equipment Condition &Ability	Ok and Sinha (2006), Zayed and Halpin (2005), Muqeem et al. (2011), Zayed and Halpin (2004)
M.2.	Equipment Availability	Palikhe et al. (2019), Alaghbari et al. (2019),Ok and Sinha (2006), Choi and Ryu (2015)
M.3.	Earth Condition	Ok and Sinha (2006), Zayed and Halpin (2005), Zayed and Halpin (2004), Woldesenbet (2005)
Labor-related		
L.1.	Labor Competence & Experience	Alaghbari et al. (2019),Ashuri et al. (2014), Offiah (2017), Heravi and Eslamdoost (2015)

L.2.	Safety & Security Condition	Palikhe et al. (2019), Alaghbari et al. (2019), Al-Zwainy (2012), Offiah (2017)
L.3.	Labor Motivation	Palikhe et al. (2019), Al-Zwainy (2012), Heravi and Eslamdoost (2015)
L.4.	Labor Availability	Palikhe et al. (2019), Alaghbari et al. (2019), Zayed and Halpin (2004), Muqeem et al. (2011)

3.2.3. Taxonomy

The primary purpose of the taxonomy in the proposed model is to categorize activities in a structured manner. This hierarchical taxonomy was developed through an extensive literature review (incorporating sources such as the CI/SfB Construction Indexing Manual (Sweeden), Uniclass (UK), OmniClass (CSI, North America), MasterFormat (CSI, North America), National Master Specification (Natspec, Australia), and The New Rules of Measurement (NMR, UK)) as well as insights gathered from domain expert interviews. Figure 5 shows the taxonomy that was generated for classifying the activities in the construction phase. Developed taxonomy comprised of 5 hierarchy levels where a total number of 100 items were included. The main categories in the taxonomy are listed as “general”, “structure”, “services”, “equipment-furnishing-fittings”, and “site-urban-open spaces”.

Once an activity is tagged with an item in the taxonomy, the parents or upper hierarchy elements of this item are also automatically assigned to the same activity. This feature helps to retrieve the desired activity more easily using the proposed taxonomy. It is worth noting that the proposed taxonomy can be modified to meet the company needs.

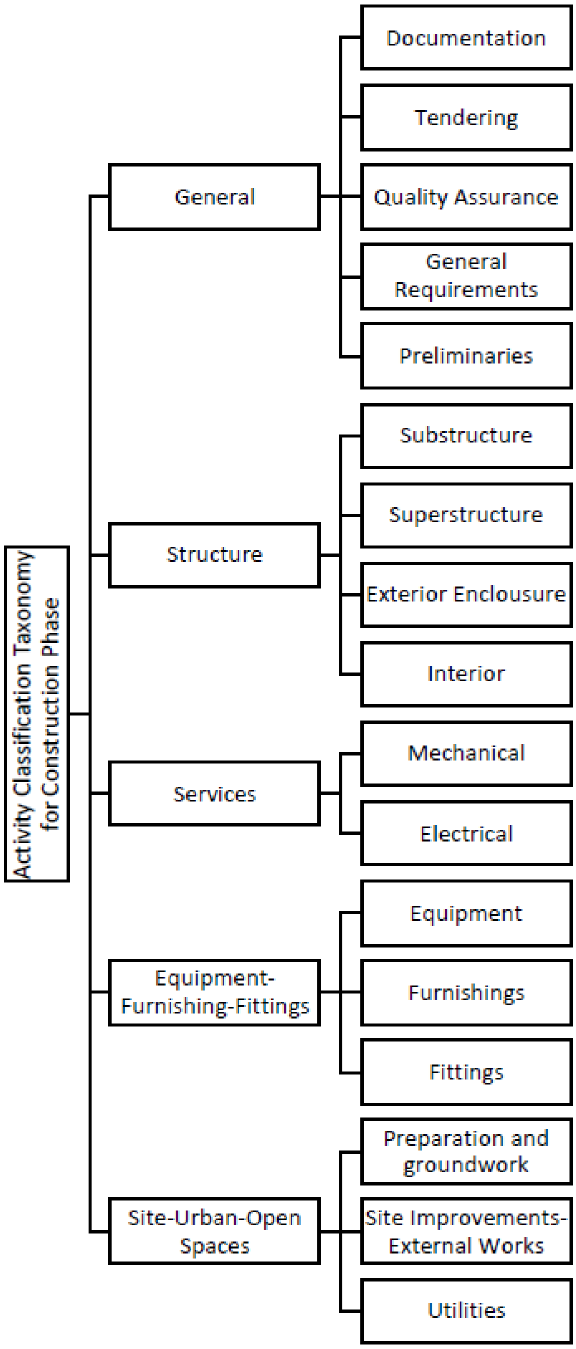

Fig. 5. Developed Taxonomy

3.3. Validation of the Lessons Learned Process Model

To validate the proposed model, interviews were conducted with four different construction professionals (Stage 2. Interviews). The proposed model was sent to the experts two weeks before the interview was conducted so that the professionals had a chance to evaluate the developed model more in-depth. After the evaluation process, the interview was held through video conferencing. The interview included several open-ended questions about the reliability, efficiency, and applicability of the proposed model. The model was revised according to the minor modifications proposed by the experts mainly about clarifications about factors and then used as the basis of the tool which will be explained in the following section.

3.4. Construction Industry Scheduling with Activity-Based Lessons Learned Tool – ConSALL Tool

ConSALL is a web-based application that can be compatible with frequently used web browsers on computers and mobile devices. The software components were programmed with Python3 (v3.6.15) programming language, and an SQL server was used to store and retrieve the required information. As it has a user-friendly interface, Django We Framework (v2.1.5) was selected for the design of the web framework. In addition, to design the website Front-End, Bootstrap Front-End Toolkit (v5.0.2) and jQuery (v3.2.1) library were preferred using Javascript programming language. The tool functions can be divided into three main parts as "administrative settings", "lessons learned information entry", and "lessons learned information retrieval".

3.4.1. Administrative Settings

The created tool provides flexibility to make necessary modifications for many settings such as adjusting the user roles by changing their responsibilities, modifying the taxonomy, and revising the factors affecting the activity productivity rate and the categories to which they belong. The proposed taxonomy and the identified factors affecting activity the productivity rate of the activities were integrated into ConSALL tool as a tagging system. As each project has different characteristics, ConSALL tool allows the users to revise the taxonomy and the factors through the editing area according to the project requirements.

The stored information in the system is confidential to the company, therefore, access to the system is provided only with the identified user names and passwords assigned by the system administrator. In the system, roles were defined to show the privileges of users in terms of allowed actions and accessibility to screens. In the proposed model, three different user roles were created as “knowledge user”, “knowledge facilitator”, and “knowledge manager”, these roles and their authorization levels were directly transferred to ConSALL tool. For instance, the “knowledge user” has the privilege to enter the new lessons learned into the system as well as search and display lessons that have already been added to the system.

In addition to these three roles, the “system administrator” role, who identifies the authorization level of the users, was created. A user who registers to the tool is automatically assigned as a “knowledge user” and has the option to create new user roles.

3.4.2. Information Entry

To record the lessons learned and activity productivity information in the tool, the initial step is adding a new project and its attributes. Projects and their attributes are created using the “projects” tab through the admin panel in ConSALL tool. On the other hand, the “activity” tab in the admin panel enables the creation of the activity by entering requested attributes about the activity. These attributes include “activity name”, “connected category”, “connected project”, “original duration”, “planned start date”, and “planned finish date”.

Once the activities and attributes are entered into the ConSALL tool, lessons learned can be recorded in the database when the activity is in progress or finished. For entering a new lesson, first, the desired activity is chosen among the recorded activities using the drop-down menu of the tool, then, the “Add Lessons Learned Information” tab is selected to fill in the related lesson learned information. LL form includes 5 different sections where detailed information about lesson learned can be entered by the user. The first section is “Lesson Learned Type”, where the type of the LL can be selected from the drop-down menu. There are two alternatives for the “Lesson Learned Type” section as “failure” or “success”. The “Event description” section is the text-free area, where users can explicitly write down the event that caused this lesson to happen. Moreover, the “Solution Description&Recommendation” section is also text text-free area, where the solutions and recommendations for the LL event can be added. The “Related Factors” section allows users to label the lesson learned with the factors to which the LL event belongs. The factor can be selected from the created factor list. This tagging process can help to easily find the desired LL in the ConSALL tool. The last section for the LL form is the “Extra Documents Link” section that enables users to upload extra documents related to LL (i.e. links, documents) into the tool. Once the required fields are filled, and uploaded to the system, it is submitted for approval. After the approval of the “knowledge manager”, the lesson learned can be visible to the other users.

On the other hand, activity productivity information can be entered by the “knowledge facilitator” using the “Data Entry Page” in the ConSALL tool. The adding process can be performed by selecting the “Add Activity Data” tab in the “Data Entry Page”. Once the “Add Activity Data” tab is selected, the tool requests “6” data that are related to the productivity of the activity. These data include “Creation Date”, “Executed Quantity”, “Man Count”, “Worked Hours”, “Unit”, and “Related Factors”. “Creation Date” is the creation date of the data, and can be identified using the calendar in the tool. “Executed Quantity”, “Man Count”, “Worked Hours” and “Unit” are the daily activity data that should be collected from the site, and recorded daily into the ConSALL tool. Also, if there exists any factor that affects the productivity of the activity, users can select the factor and its impact from the “Related Factors” section in the tool. Figure 6 presents the user interface for activity productivity information in the ConSALL tool.

After all required data are submitted to the tool, the system calculates the productivity of the activity using Equation 1. Once the data-entering process is finished, the "knowledge facilitator" should select the "Finish Activity" tab on the tool. Thereafter, "Actual Start", "Actual Finish", "At Complete Duration" and "Unit" information of the activity appear on the "Activity Search" page. For the "Actual Start", the system automatically receives the initial creation date of the activity productivity information. On the other hand, "Actual Finish" is the last creation date for the activity productivity information. In addition, it is enough to enter the "Unit" of the activity to the "Data Entry Page" only for the first day of the activity, for the remaining days, the system automatically uses the same unit for the "Unit" of the activity.

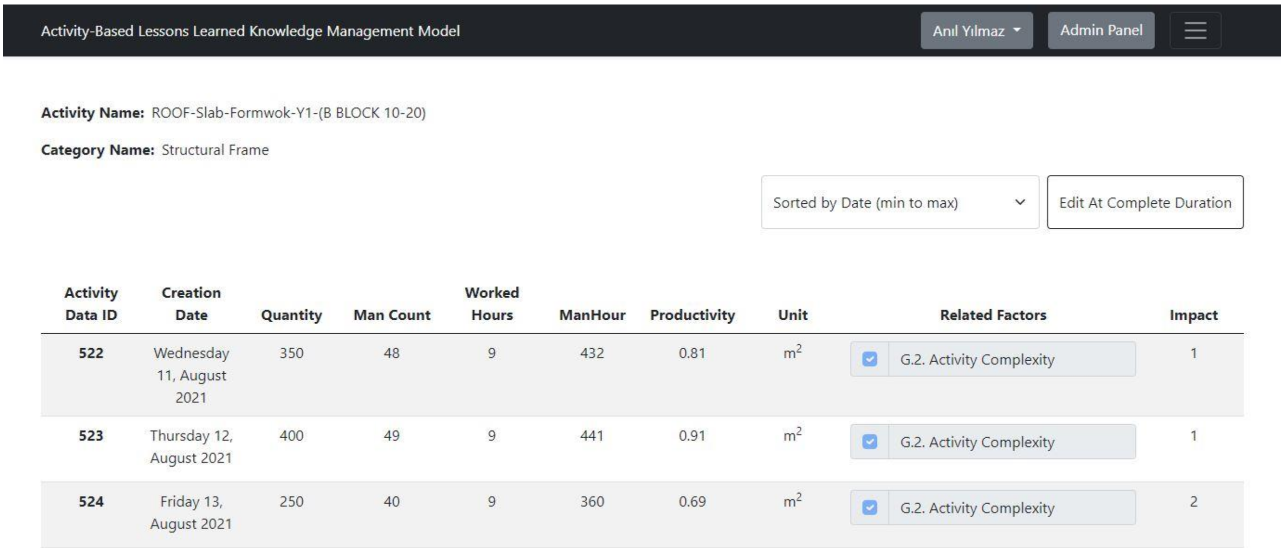

Fig. 6. User interface for entering activity productivity information in the ConSALL tool

3.4.3. Information Retrieval

Users can access the desired lessons from the system using three different search options, namely "filtering based on activity attributes", "filtering based on taxonomy", and "filtering based on factors affecting the productivity of activities".

"Filtering based on activity attributes" can be performed using three attributes: "Activity Name", "Project Country", and "Activity Unit", as shown in Figure 7. "Activity Name" and "Project Country" are activity-related qualitative information that are defined in the creation of the activities, whereas "Activity Unit" is identified in the generation of activity-related quantitative information. In addition, the tool also allows users to search using multiple filters, which helps users to narrow down the search results, and reach the desired information more easily. For instance, a user can access the lessons and quantitative information about "Activity X" that took place in "Country Y". When "Activity X" and "Country Y" are selected in the Activity Search screen, the tool provides all results that meet the joint list of two attributes.

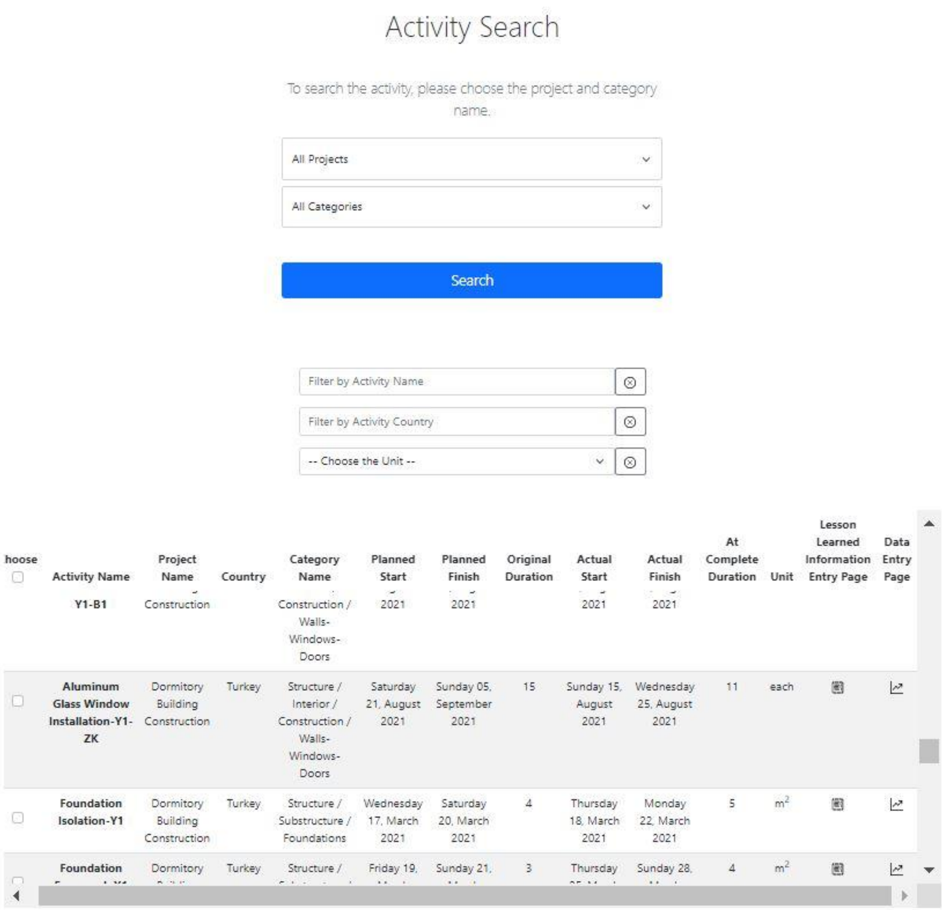

Fig. 7. Filtering options based on activity attributes in the ConSALL tool

As mentioned previously, all activities are tagged according to their categories using the extendable tag tree, whilst entering them into the system. So, the second search option uses these tags to filter the activities. In that search mechanism, the project is selected from the drop-down menu that shows all projects that have been previously entered the system. Then, by selecting the category from the drop-down menu, users can access all activities that belong to the selected category. The tool also allows users to perform secondary search, in which filter-search can be combined with tag-based search. This feature helps users to access the intended tags with different attributes. For example, the user can search the activities that belong to the "Substructure" category and took place in "Country A".

The last search option is based on the factors affecting the productivity of the activity. The tool provides the ability to users to filter the activities by selecting not only the factors but also the impact of the selected factors from the drop-down menu. Moreover, users can specify the factors to be excluded as well as factors to be included for filtering. For example, the user can search the activities that are affected by "Weather Condition" with an impact rate of less than 3, and "Planning and Schedule Concern" without any limitation for the impact rate. As a result of this search, the search engine provides a list of activities that satisfy the desired conditions.

3.5. Testing and Validation of ConSALL

Testing and validation of the tool were performed in two successive steps. In the first step, the tool was tested by the research team comprising the authors of this paper, using black-box testing methods. Black-box testing methods help to evaluate the functionality of the tool, ignoring the internal details of the software (Mirshekarlou et al., 2021). For this purpose, a real dormitory project that consists of 8 floors and 1500 activities, was chosen as a case study to demonstrate the processes for the utilization of the ConSALL tool. Critical Path Method was used while preparing the baseline schedule of the case study. In addition, hypothetical lessons and quantitative information were created for each activity. Once the research team entered the required information about the project and activities into ConSALL, they tested the features of the tool including search options, calculations for the productivity rates of activities, and privileges of users in terms of allowed actions.

In the next step, interviews were carried out with two professionals from different companies for the validation of the ConSALL tool (Stage 3. Interviews). Before the experts were using the tool, an informative session was arranged. In this session, first, the proposed model was presented. Then, the tool and its functions were introduced by using the case study. After using the ConSALL tool, the experts were asked their opinions about the proposed system.

According to the responses of the experts, the strengths and weaknesses of ConSALL are listed as follows:

- Both experts mentioned that the tool meets all requirements and features that were stated in the process model. Expert 1 stated that the user-friendly interface of ConSALL can be very helpful in reaching qualitative and quantitative information about similar activities. Expert 2 pinpointed that although a huge number of activity information from the previous projects decreases the efficiency of the model, different search options to retrieve the information can be very useful in reaching the desired information efficiently. In addition, according to the experts, customizable taxonomy can help to meet the needs of a company.

- Both experts recommended a synchronization function between ConSALL and popular construction planning software to save time which also increases the efficiency of the tool. It was also declared that this synchronization property reduces the possibility of loss of information. Expert 2 also conveyed that an export option also is required, where the users can transfer the filtered or desired information from the ConSALL tool to other platforms such as Microsoft Excel.

- Both experts underlined that deleting the miswritten information in the “Data Entry Page” of the tool is complicated as it can only be deleted in the admin panel. Expert 1 also stated that after choosing the “Finish Activity” option in the “Data Entry Page”, only the admin can correct the mistakes through the admin panel. This deleting process was thought to decrease the efficiency of the tool.

- Web-based structure of the application was appreciated by the experts. However, Expert 2 criticized the design of the tool in terms of switching properties. It was stated that when a user wants to return to the previous page, the website automatically directs to the index search page. This is time-consuming and causes extra effort to reach the desired page.

Results show that ConSALL is appreciated by the experts, and can eliminate the loss of experience gained in past projects. The experts believe that the proposed tool may become more promising in disseminating knowledge about scheduling within the company. It is also thought that the success of this system highly depends on the company culture. According to the experts, the lack of training can be a potential barrier for implementation of tools like ConSALL.

4. Conclusions

This research aims to develop an activity-based lessons learned process model for scheduling (ALLPMS) to support scheduling decisions in construction companies and a web-based tool to facilitate the features of the proposed model. Research findings show that current scheduling practices have not effectively used data from previous projects, and schedules are generally developed solely based on the experiences of the schedulers. An activity-based lessons-learned tool that has the capability of capturing, storing, and reusing, is needed to manage lessons-learned information efficiently. As the quality of the lessons to be entered into the tool is critical for the system efficiency, the tool should be centralized and include a user management system with approval mechanisms. To that end, a web-based tool, namely ConSALL, was developed to improve scheduling practices in construction companies.

The significance of this research stems from the potential benefits of ConSALL to the construction industry. The practical implications of ConSALL are substantial, as it minimizes the recurrence of past mistakes, enhances organizational learning for more accurate duration estimations, and facilitates the creation of realistic schedules. By fostering better decision-making and more efficient project management, ConSALL contributes to improving scheduling practices within the industry.

Moreover, the customizable features of ConSALL offer organizations the flexibility to tailor the tools to their specific needs. This adaptability ensures that they can scale across various project types and organizational structures. Additionally, with the ability to categorize and search activities based on specific attributes, ConSALL increases the efficiency of retrieving relevant lessons learned and scheduling information. This capability enables decision-makers quickly identify similar activities, apply valuable insights to current projects, and make more informed decisions, ultimately enhancing project execution.

The theoretical contribution of this study lies in being the first to develop a system that enables organizations to systematically capture, store, and reuse scheduling information. By addressing this gap, the study enhances the theoretical understanding of knowledge management in construction scheduling.

On the other hand, there are some limitations of the tool and the proposed model. One of the limitations is the data security of the system. It has not been given enough attention to data security since the ConSALL tool is used as a prototype. Therefore, companies should ensure stronger data protection measures before implementing the system in real-world projects.

The lack of interoperability is another limitation of this study. Currently, ConSALL is unable to communicate with other commonly used tools, which prevents the import or export of activity-related information. If interoperability between ConSALL and popular project planning software can be established, the tool can retrieve the activity information from the planning software which can increase the system efficiency and eliminate the time-consuming process. Future studies could focus on providing interoperability between ConSALL and other widely used project planning software like Microsoft Project or Primavera.

The other limitation of this research is that the user inputs have a significant impact on the quality of the lessons. As the model performance is highly dependent on captured information, the organizations should provide detailed information about the LL entry process by framing the content of the information. To address this, organizations should develop clear guidelines and structured templates for users, helping them to enter comprehensive and consistent data.

In this research, the ConSALL system was tested using hypothetical lessons and quantitative information. To enhance the system's usability and effectiveness, a comprehensive lessons learned (LL) database is needed as part of its future application.

Finally, it is believed that the model and tool can significantly benefit from development in AI technology. AI algorithms can be used to retrieve information and predict durations if enough number of data is stored in the database. ConSALL can provide a template for further developments of AI for automated scheduling.

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