Automation of Decision-Making Processes in Construction Management

Roman Oldenburg

Technical University of Darmstadt, Institute of Construction Technologies and Management, r.oldenburg@baubetrieb.tu-darmstadt.de

1 Abstract

An increasing number of input variables for management information systems (MIS) in construction are now being captured automatically and in near real-time. To fully harness this potential, MIS must analyze these data at the same frequency and generate concrete action recommendations. After all, continuously collecting information holds little value if it is only evaluated at long intervals. By automating assessment and decision-making processes, construction projects can be managed more efficiently, enabling more-informed and timely decisions. This approach is grounded in control engineering principles and the System Dynamics methodology. The goal is to develop a management tool that supports project managers in answering key questions: What interventions are necessary, at what intensity, for how long, and in what sequence, to bring the current project status as close as possible to the desired target state? This is achieved by utilizing existing sources of information, as the necessary datasets are already embedded in various management tools, eliminating the need for additional structures.

2 Introduction

Recent advancements in construction engineering and management (CEM) research have intensively focused on automating data collection to monitor construction processes using multisensor systems.[1] Such technologies to potentially measure performance indicators on construction sites in real-time are meanwhile rapidly emerging with declining costs.[2] These initiatives primarily seek to minimize labor expenses, enhance accuracy, and enable frequent assessments of planned versus actual performance. However, generating real-time target-actual comparisons is only the first step in the controlling process. The critical next step involves analyzing and evaluating deviations, which requires contextualizing the data with a wide array of relevant project parameters. These parameters include tangible aspects such as cost, design, schedule, payments, claims, resource consumption, quality, cash flow, change orders, health and safety aspects (HSE), and contractual factors. Additionally, intangible elements such as work pressure, climate conditions, worker skill levels, team motivation, learning curves, security aspects, and other unique project-specific events must also be considered before decisions can be made.

While real-time performance data is intended to facilitate decision-making, its continuous availability may inadvertently lead to ongoing analysis efforts, increasing the workload and pressure on decision-makers given the complexity of the evaluation process. As the frequency of data updates increases, decision-makers might find themselves required to continuously analyze and interpret the latest information to ensure their decisions are based on the most relevant and current data. Such constant need to evaluate new datasets can rapidly become overwhelming. Therefore, research should focus on

[1] Rao et al. (2022).

[2] Navon and Kalman (2024), p. 1290.

developing automated systems that not just generate real-time data but help assess project status and support decision-making, easing the burden on decision-makers.

All structured information that project managers rely on for decision-making is already embedded in various management tools. These datasets accumulate over time as project activities progress, tracking resource usage and compiling key project metrics. Together, they describe the project's current state. Project managers assess this data, combining their evaluations with implicit experience and explicit policies to make informed decisions that help steer the project toward its intended objectives.

System Dynamics identifies a universal stock and flow structure underlying social, economic, industrial, and-political organizations. This perspective integrates the fragmented functional aspects of formal organizations into a structure of dynamic flow rates and responsively changing levels of accumulation. These accumulations, termed stocks, serve as reference points for decision-making. They encompass all critical project resources, including labor, finances, materials, orders, equipment, information and time. Stocks change gradually through inflows and outflows.[3]

In System Dynamics, decisions act as the primary control mechanisms of these flows, determining the rate at which stocks change over time. In SD diagrams, decisions are even represented using a control valve symbol, emphasizing their role in regulating resource movement. Figure 1 illustrates this concept, showing how decisions regulate the flow rate from a source stock to a destination stock based on available information.[4]

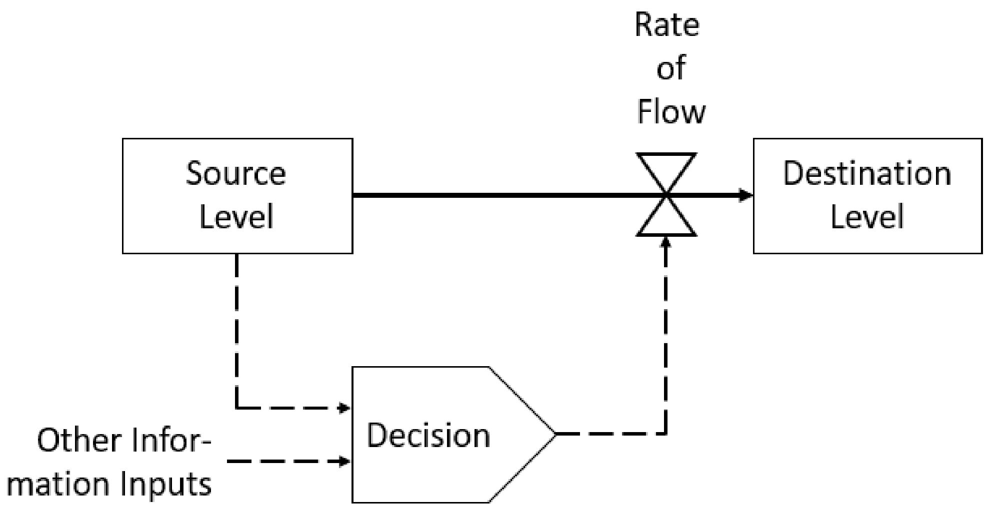

Figure 1: The Decision as a Controller based on Roberts (1999)

Mapping the decision-making process in construction project management using System Dynamics not only integrates disparate management tools into a cohesive system, addressing a critical practical need, but also helps mitigate the cognitive challenges of managing complex projects. Applying control theory to such a model ensures that decision-making is optimized within the system's constraints.

3 Problem Statement

Large scale construction projects are extremely complex, highly dynamic and involve multiple feedback processes.[5] Our mental models of such systems are often simplistic and unreliable, having narrow

[3] Roberts (1999), p. 395.
[4] Roberts (1999), p. 395.
[5] Sterman (1992), p. 6–7.

boundaries and short time horizons, ignoring dynamics and feedback.[6] Traditional management techniques often get criticized for showing similar deficiencies.[7] [8] [9] [10]

The current developments in automated project performance control reveal two fundamental problem areas. First, research primarily focuses on automated data collection and real-time target-actual comparisons. However, simply juxtaposing target and actual values does not provide actionable insights for decisionmakers. Only by analyzing deviations and contextualizing them with additional, often scattered project parameters can a comprehensive assessment of the project status be achieved. In this area, automated solutions remain insufficient.
Project performance is usually measured in terms of installed quantities, cost, schedule, productivity, resource consumption, etc. Since the collection of such data traditionally involves lots of manual processes and therefore is slow, inaccurate, and error-prone, it comes as no surprise, that research has intensively focused on developing technologies to automatically capture the required data. To obtain more timely and accurate results, managers would otherwise have to invest an excessive amount of time in data collection, which would shift their focus away from overseeing and managing operations.[11]

What falls short is, that automating the collection of the data without simultaneously finding solutions to automatically process and evaluate the data will not produce the desired result of reducing work pressure and improving decision-making.

The problem is illustrated in Figure 2. Loop B1 highlights that as work pressure on project managers increases in order to obtain timely and accurate information, automated data capturing is increasingly seen as a solution. The expectation is that improved data quality and higher availability (i.e., reduced latency between the occurrence of an event and its corresponding update in the reporting systems) will ultimately alleviate work pressure.

However, as Loop R1 indicates, an important side effect is overlooked. Automating data capture also means data is collected more frequently—ideally in near real-time. This results in an increased evaluation effort for project managers, who are now required to constantly update reports and analyses to ensure their decision-making is based on the most current data. Instead of alleviating work pressure, the implementation of automated data capturing may, over time, amplify it.

Loop B2 illustrates the implementation of automated data evaluation systems as a potential mitigation. As construction project organizations encounter the challenges outlined, the demand for automated data analysis tools is likely to increase. These systems help alleviate the heightened evaluation workload caused by high-frequency data collection, restoring balance to the workflow. Over time, this approach may also lead to the initial goal of reducing overall work pressure on project managers, as automating data collection is only one part of the solution; automating data analysis is the other.

[6] Ford and Sterman (2003), p. 211.

[7] Abotaleb and El-adaway (2018), p. 1.

[8] Peña-Mora et al. (2008), p. 703.

[9] Lyneis et al. (2001), p. 238.

[10] Rodrigues and Bowers (1996), p. 214.

[11] Navon and Kalman (2024), p. 1290.

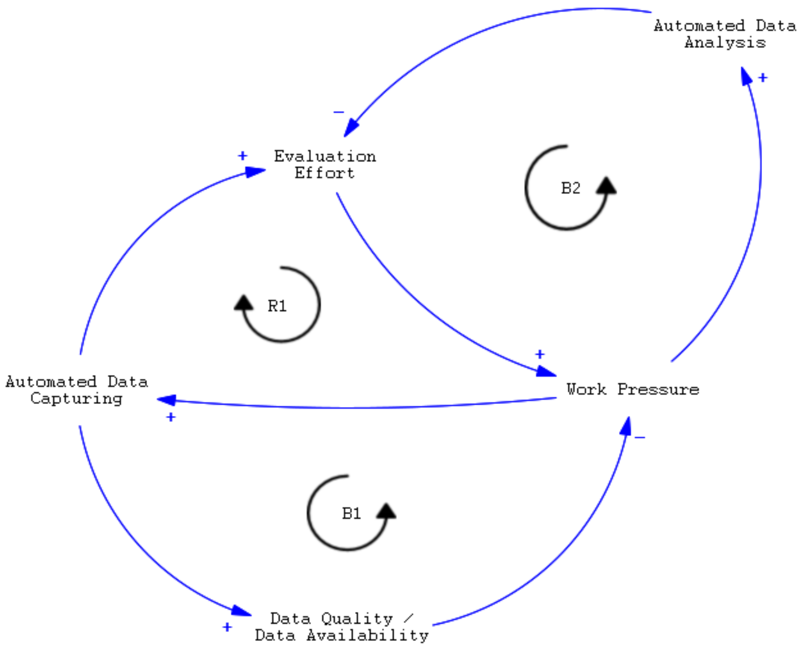

Figure 2: Automation in Project Performance Control

The second problem area lies in the level of granularity in data collection and the computer tools used for processing. The overwhelming complexity of construction projects is increasingly addressed with more intricate tools and models, which exacerbates the issue rather than solving it. Traditional Project Performance Control frameworks aim to align project progress with the initial plan as closely as possible.[12] This approach is reflected in previous research on developing model-based project management tools, which tend to favor increasingly complex models. The belief is that adding more detail results in more accurate models, leading to a greater understanding of the project.[13]

This attempt to reduce uncertainty by focusing on minute aspects is ultimately counterproductive. While precise calculations may provide a sense of certainty[14], they are often impractical for managing the dynamic nature of day-to-day operations. In complex, dynamic environments – such as construction projects – where outcomes depend on numerous interconnected processes, a high-level approach is often more efficient than excessive focus on minutiae.[15] Management tools must be based on the understanding that execution will remain unpredictable in detail beyond a few steps into the future, as construction projects inherently approach chaotic conditions.[16]

In-depth planning for immediate or near-future tasks, the day-to-day operations, is the responsibility of foremen and construction managers. They must be well-informed about the teams, tasks, locations, work sequences and construction methods involved in the actual execution of the work. Project managers, on the other hand, should not be focused on such specific aspects. Instead, their role is to take a holistic view of the project, ensuring the necessary preconditions for successful daily operations are in place—such as means of production, design, procurement, permits, access rights, safety measures, approvals, and contracts. The options available to managers for actively steering the project remain limited to broader actions, including adjustments to work hours, staffing levels, equipment allocation, work pressure, or shifting schedules. As such, models underlying management tools should also operate at a relatively low level of granularity to begin with.

[12] Navon and Kalman (2024), p. 1290.

[13] Rodrigues and Bowers (1996), p. 213.

[14] Dörner (2001), p. 251.

[15] Dörner (2001), p. 245.

[16] Bertelsen, p. 5.

As Jay W. Forrester noted in a 1991 interview for the McKinsey Quarterly, "*People running management information systems have a tendency to make information available in more and more detail and variety to more and more people until everyone is overwhelmed with information. Information pollution may be our most serious form of pollution. Excess information focuses attention on information streams that are not appropriate to the decisions being made. The whole area of MIS needs to be designed using system dynamics, so that models can reveal the effect of having or not having certain information streams. The result would be to discontinue much of the present information flow and to supply a few critical information inputs that are not now available*".[17]

Forrester's statement highlights the core issue: The need for a Management Information System that prioritizes key information stocks over excessive detail, ensuring usability and acceptance by managers. These information stocks already exist within various traditional management tools—no new structures need to be created. Since managers currently rely on these for decision-making, they provide a sufficient foundation for the system to be developed here. While automatic data capture and real-time updating of these information stocks fall outside the scope of this research, this study focuses on designing a system that integrates traditional project management tools with formalized mental models of decision-makers to automatically assess project progress and identify necessary control measures. The system should be highly adaptable, allowing for efficient calibration to different construction projects from the perspective of contractors, rather than that of clients or authorities. Figure 3 illustrates the research approach.

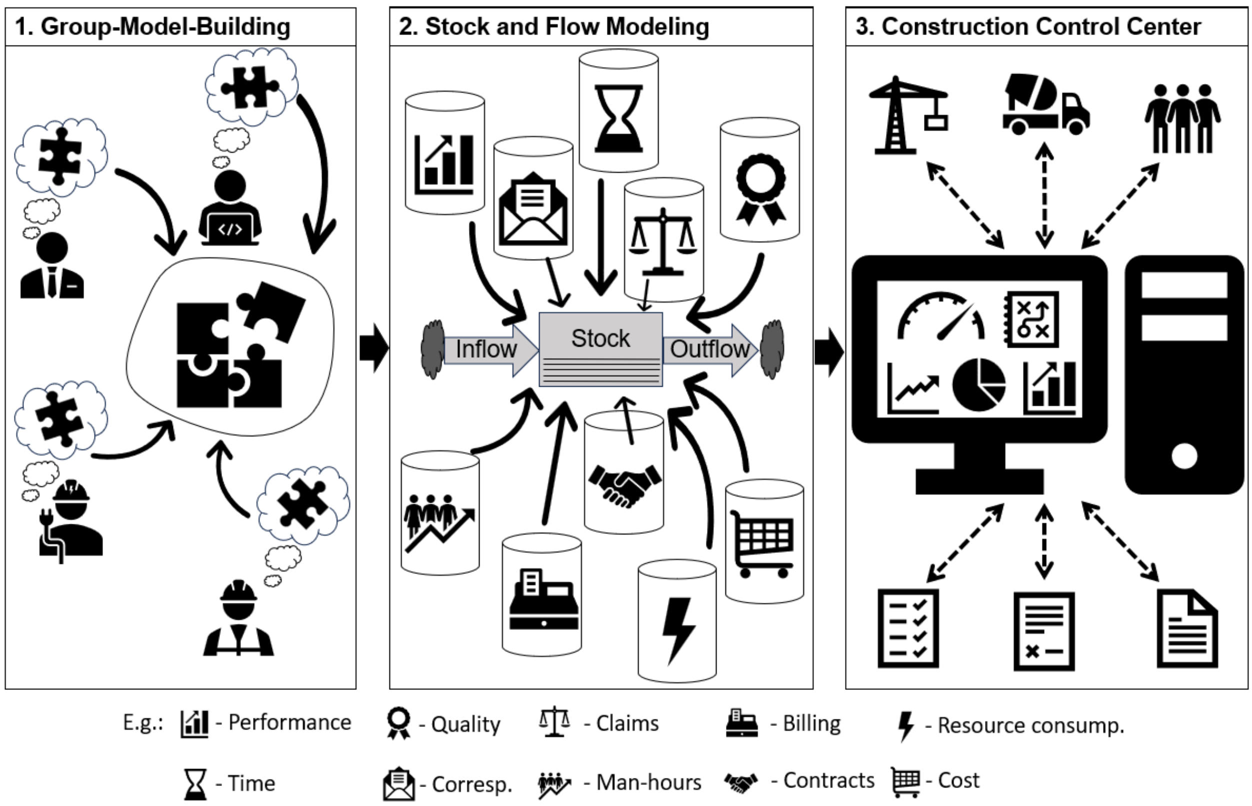

Figure 3: Illustration of the research concept

[17] Keough and Doman (1992), p. 8.

4 Current State of Research

Extensive research has been conducted on the application of System Dynamics (SD) modeling in project management, with notable contributions from Cooper (1980), Rodrigues and Bowers (1996), Rodrigues and Williams (1998), Ford and Sterman (1998), Richardson and Pugh (1999), Lyneis et al. (2001), Park and Pena-Mora (2003), Lee et al. (2005), Ford et al. (2007), and Leon et al. (2018), among others.

The literature reviews on SD applications in Project Management by Lyneis and Ford (2007), Abotaleb and El-Adaway (2018), and Kedir et al. (2023) suggest that the factors driving project dynamics are already well understood.[18] The research focus should now shift toward controlling these dynamics—identifying which managerial levers to adjust, in what sequence, for how long, and to what extent, to achieve performance targets.[19] Models should not only assess project progress but also anticipate resource requirements.[20] This is precisely the objective of the research presented in this paper, which aims to explore and address these aspects of controlling project dynamics and managing performance targets.

Different performance measures—such as schedule, cost, quality, and scope—can become critical at various stages. While the management of these factors differs, they are interdependent, and the interactions between them significantly influence project outcomes. Further research is needed to explore these interdependencies, particularly in the context of decision-making by construction project managers.[21] The current study focuses on this issue, aiming to map the decision-making process of construction project managers, which usually takes into account all the key performance measures.

A recurring theme in literature reviews is the limited application of SD models to real-world construction projects.[22] [23] Additionally, integrating SD models with other project management tools has been identified as a promising research direction.[24] This could enhance practitioners' understanding of SD and increase its practical applicability.[25] This study aims to contribute to both of these areas.

5 Methodology

This study adopts a Design Science Research (DSR) framework, which aims to develop artifacts that address practical problems.[26] Here, the artifact is a Management Information System (MIS). Figure 4 illustrates the research process structure, showing a sequence of five activities, where the output of each activity serves as the input for the next. While presented as a linear process for clarity, iterations can occur at any stage. For instance, insights gained during the demonstration phase may prompt a return to the requirements phase, facilitating continuous refinement through practical testing. The five activities are framed by two boxes: the top box outlines the scientific methods applied in this study, while the bottom box presents the knowledge base supporting the research.

[18] Lyneis and Ford (2007), p. 183.
[19] Lyneis and Ford (2007), p. 184.
[20] Abotaleb and El-adaway (2018), p. 12.
[21] Lyneis and Ford (2007), p. 184.
[22] Lyneis and Ford (2007), p. 184.
[23] Kedir et al. (2023), p. 17.
[24] Lyneis and Ford (2007), p. 185.
[25] Kedir et al. (2023), p. 17.
[26] Johannesson and Perjons (2021), p. 8.

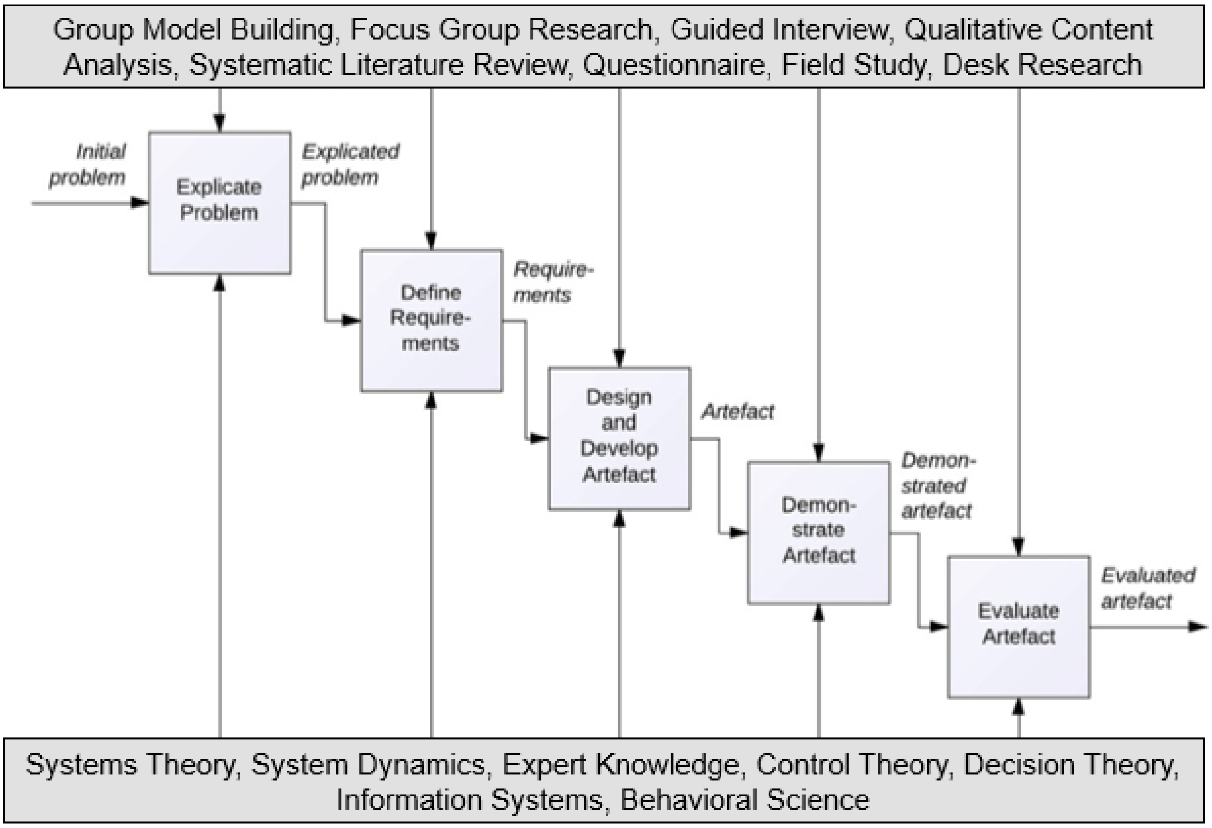

Figure 4: General Research Design based on Johannesson und Perjons (2021)

The initial problem, outlined in the Problem Statement, is the need for an MIS to automate the assessment of scattered data from various management tools currently in use. Initial field surveys and expert interviews confirm the general demand for such a system.
Management Information Systems are better understood, designed and controlled through the feedback structure approach of System Dynamics. Its basic concepts of system goals, measurement of performance relative to the goals, and reaction to deviations from these goals underlie every organization.[27]
Each has objectives, beliefs about its current status, and policies and procedures for decision-making and actions aimed at achieving its goals.[28] System Dynamics asserts that organizations are most effectively managed from the control system perspective, as shown in the feedback process in Figure 5.[29]

[27] Roberts (1999), p. 389.
[28] Roberts (1999), p. 393.
[29] Roberts (1999), p. 394.

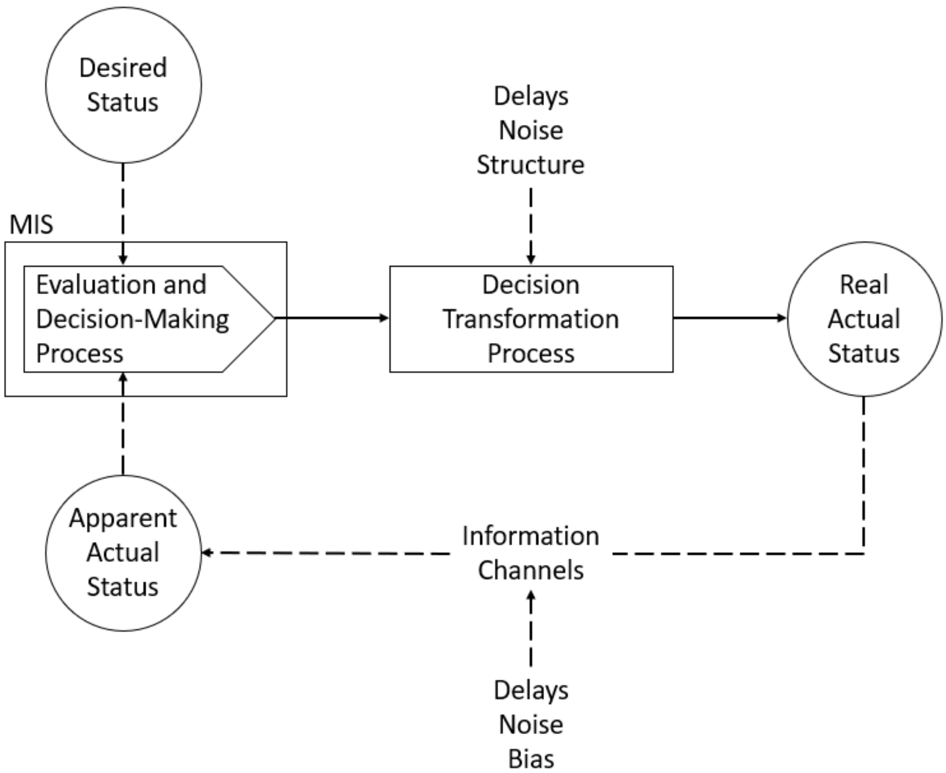

Figure 5: MIS within the Control System Structure of Organizations based on Roberts (1999)

The MIS examined in this research uses both the desired and the apparent actual status as inputs. It consists of an SD-model that maps the evaluation and decision-making process in construction management. A feedback controller helps identify control measures most likely to align the target with actual progress (see also Figure 7). The desired status is first determined through work preparation and tendering efforts during the bidding process, including cost estimates, timelines, invoice schedules, and resource histograms. As the project progresses, these are updated. The apparent actual status represents the information available in existing management tools, whether gathered through traditional manual methods or modern automated technologies.
The term "apparent" acknowledges that measured progress may differ from real progress due to delays, noise, and biases in information channels. The transformation of decisions into outcomes is driven by a complex interplay of organizational, human, technological, and market dynamics. However, the structure of this process is often obscured by randomness, noise, and significant time delays between causes and their effects.[30]

The problem can be further explicated by defining the need for a System Dynamics model that captures the forecasting procedures for cost, quality, and schedule. These forecasts form the primary basis for managerial decision-making, guiding actions to keep projects on track. At its core, this approach directly addresses the well-documented issue of project overruns.[31]

The MIS must be a digital tool capable of mirroring the assessment of project parameters. It should evaluate and forecast project status automatically by drawing on actual data from existing management tools, necessitating seamless interfaces with these tools. Additionally, to support decision-making, the system must estimate the sequence of managerial actions, their respective intensity, and duration, guiding project status toward its desired state. The results should be presented through intuitive, visually accessible formats to enhance usability. Moreover, the system must allow for easy simulation of different management interventions, providing insight into their potential effects. Ultimately, its primary function

[30] Roberts (1999), p. 393.
[31] Flyvbjerg (2009), p. 346.

is to help reduce project overruns. More detailed requirements will be established through upcoming field studies.

The development of the artifact will be an iterative process, combining desk research with various empirical research methods, such as Group Model Building sessions, interviews, or questionnaires.

The demonstration of the artifact will happen against three functional hypotheses and the defined requirements through two field studies: one on a large-scale skyscraper project and another on a major highway project. The functional hypotheses, which serve as the foundation of this study, are explained in detail later in the text.

The evaluation phase will assess these field studies to determine how well the artifact meets the predefined requirements.

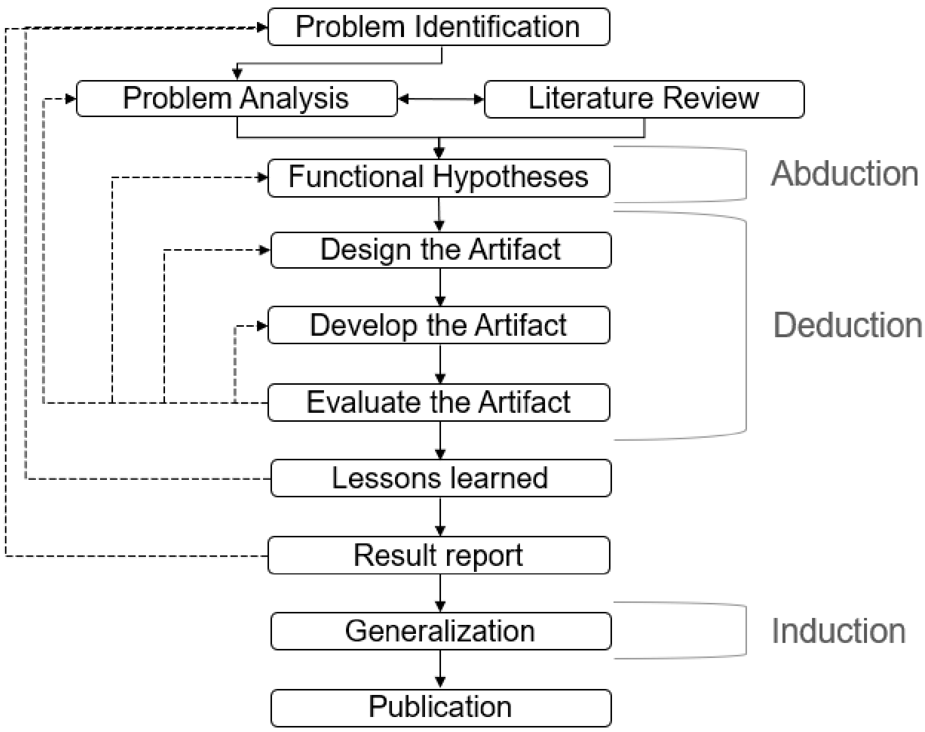

Figure 6: Detailed Research Design based on Dresch et al. (2015)

Figure 6 presents the detailed research design. After identifying the problem, a comprehensive literature review is conducted to gain a clear understanding of the matter and the current state of research. The functional hypotheses are then derived abductively from the acquired knowledge. Three functional hypotheses are proposed:

1. *If stocks (state variables) describe the state of a dynamic system, and the control tools used in Construction Engineering Management (CEM) describe the project state, then the information stored in these tools can be integrated as stock variables into a System Dynamics (SD) model. The state vector z can be uniquely determined at any time t>0, given the initial states z(t0) for each state variable and the input vector u(t0, t) over the interval (t0, t).*

   In assessing a construction project's current state, management gathers various types of information, such as performance achieved, amounts invoiced, costs incurred, payments received, resources consumed, and time elapsed. These data, accumulated over time, define the project's state. Managers aim to control the incremental changes in these states through their actions, which are guided by their mental models. Mental models reflect their understanding of the cause-and-effect relationships among the system's states. Policies, whether implicit or explicit, establish the decision rules that determine managerial actions based on system states and information streams.

In System Dynamics, the state of a system is defined by its state variables, which accumulate over time. These state variables (stocks) change incrementally, with the rate of change controlled by action variables (flows). Action variables represent decision rules (policies) that are based on the current state of the system and its cause-and-effect relationships.

Given this clear analogy, System Dynamics is an ideal method for mapping the managerial decision-making process in construction project management.

2. *If the dynamic behavior of the system can be mathematically described, a feedback controller, based on control theory, can be developed. This controller would adjust the control inputs in such a way as to bring the current system state closer to the desired state (the reference).*

   Once the system's dynamics are formalized, the next step is to align actual forecasts of key variables, such as cost and time, with their reference values. The reference values represent the predicted behavior over time of key variables, as initially determined during work preparation and tendering, and subsequently updated throughout project execution. Figure 7 shows the general block diagram of the control circuit.

   Based on the understanding of the system's dynamics, the feedback controller determines the necessary control inputs, including the sequence, duration, and intensity of the managerial actions required to align the systems actual state and forecast with the desired behavior over time. Since the model is simplified and inherently probabilistic, decision-making under uncertainty could play a significant role. However, as the values of most or all state variables are continuously monitored, the model may gradually and partially calibrate itself over time.

   This enables automated decision-making while addressing the typical limitations and biases inherent in human judgment when addressing complex problems.

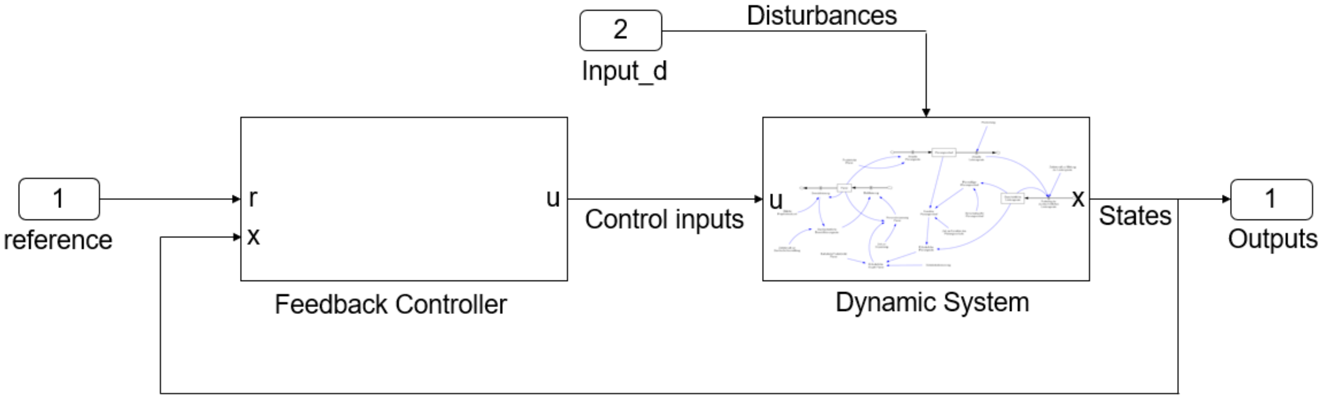

Figure 7: Feedback Control of the Dynamic System

3. *If a formal description of the dynamic system behavior and an effective feedback controller are in place, both can be integrated into a Management Information System for practical application.*

   The goal of Design Science Research projects is to create an artifact that is practical and useful for practitioners in their day-to-day operations. In this research, the artifact will take the form of a Management Information System (MIS). An MIS is a digital tool designed to support decision-making and improve business processes. While the specific requirements are still being refined through ongoing surveys, it’s important to note that the development of a fully marketable product is not the focus of this study. Instead, the aim is to demonstrate the general feasibility of the concept by testing the defined functional hypotheses and requirements. Final details, such as the user interface and IT architecture, may not be fully realized within the scope of this research.

Based on the problem understanding and the three functional hypotheses, the artifact will deductively be conceptualized and developed, as shown in Figure 6. The dashed lines in the figure indicate potential iterative steps in the process. Once the functional testing phase is complete, the lessons learned, insights, and results will be documented. These findings may lead back to the problem identification phase for further refinement or future research. The knowledge generated will be generalized inductively, and the final step will involve publishing the results, marking the conclusion of the project.

6 Initial Results

A filed study was conducted on a large-scale skyscraper project to examine the tools used by managers and whether they can be interpreted as stocks in the context of System Dynamics. The tools employed in the project typically contain all the quantifiable information needed to assess the current project status. They reflect the typical incremental development over time, meaning they evolve gradually rather than showing instantaneous changes. If the project were paused, these tools would retain their most recent aggregated level (information on the latest progress), serving as a memory until the project continues. In this sense, they function as state variables that describe the system's status, making them qualify as stocks within the framework of System Dynamics.

Qualitative System Dynamics (SD) models were developed in collaboration with two distinct groups of construction practitioners to gain initial experience in leading and moderating group model-building sessions. One group consisted of two to three participants, while the other included five to seven. A total of seven workshops were conducted, each lasting for approximately two to three hours. Various methods were applied and tested during these workshops, resulting in the acquisition of valuable knowledge and experience in explaining, moderating, steering, and managing groups of construction professionals. Furthermore, important professional connections were established, which will be beneficial for accessing relevant projects and practitioners in later stages of the research and development process. Results were documented in individual workbooks for each workshop.

In a field survey of 26 practitioners, we sought their assessment of the following questions (amongst others):

Q1: If construction progress monitoring is to be carried out continuously and automatically in the future (e.g., using drones, imaging, or tracking), this will likely lead to an increased workload for site management personnel. The continuous collection of new data will require ongoing analysis and updates to reporting systems. Therefore, research and development should not only focus on the automated capture of construction progress but also on the automated assessment of the current state and the prediction of development trends.

Q2: The subject of research at the Institute for Construction Management at TU Darmstadt is a tool for integrating all scattered information (performance status, billing status, planning status, change management, resource consumption, order status, schedule status, etc.). This enables project status assessments to be carried out at shorter intervals (ideally in real-time). Forecasts based on the available information are generated automatically. As a result, both the current project status and development trends can be continuously determined and visualized in the form of a dashboard. The foundation of this tool is a mathematical model of the mental (implicit) decision-making and evaluation rules of key decision-makers. In the event of deviations from the target, the most promising corrective actions (control measures) can be suggested based on all recorded interactions, taking into account non-linearities and long-term effects. Such a tool would be...

Among the 26 participants, 24 work for large construction corporations with more than 250 employees, while two are employed by medium-sized companies with between 50 and 249 employees. One-third of the respondents identify with the building sector, another third with infrastructure, and the final third work across both sectors. Their professional roles range from construction managers and technical managers to project managers, area managers, and executive managers. The survey results are presented in Figure 8 and Figure 9.

Figure 8 illustrates that four out of five practitioners agree or strongly agree with the author's problem statement. They believe that automatically capturing data in near-real-time may increase the workload for practitioners, rather than providing the anticipated relief. The continuous availability of up-to-date data will require ongoing analysis, and as long as no robust solutions for automating this analysis are in place, project staff will be required to conduct this work manually.

Figure 9 highlights a clear pattern of responses regarding the perceived usefulness of a tool like the one described in this research. Again, four out of five respondents consider such a tool to be "very helpful" or "somewhat helpful".

However, both questions could be considered leading, as they frame a vivid problem and an ideal solution, which may make it difficult for participants to respond negatively. The purpose of these questions is to assess expert opinions on the tool's potential helpfulness, based on their understanding of its function. To fulfill this purpose, it was crucial to clearly describe the tool to ensure that participants fully understand the questions. These results should not be generalized; rather, they are intended to confirm the current direction of our research. Nonetheless, care was taken to avoid emotionally charged language in the questions, minimizing any undue influence on participants. The response options were evenly distributed between positive and negative, ensuring no bias toward a particular direction.

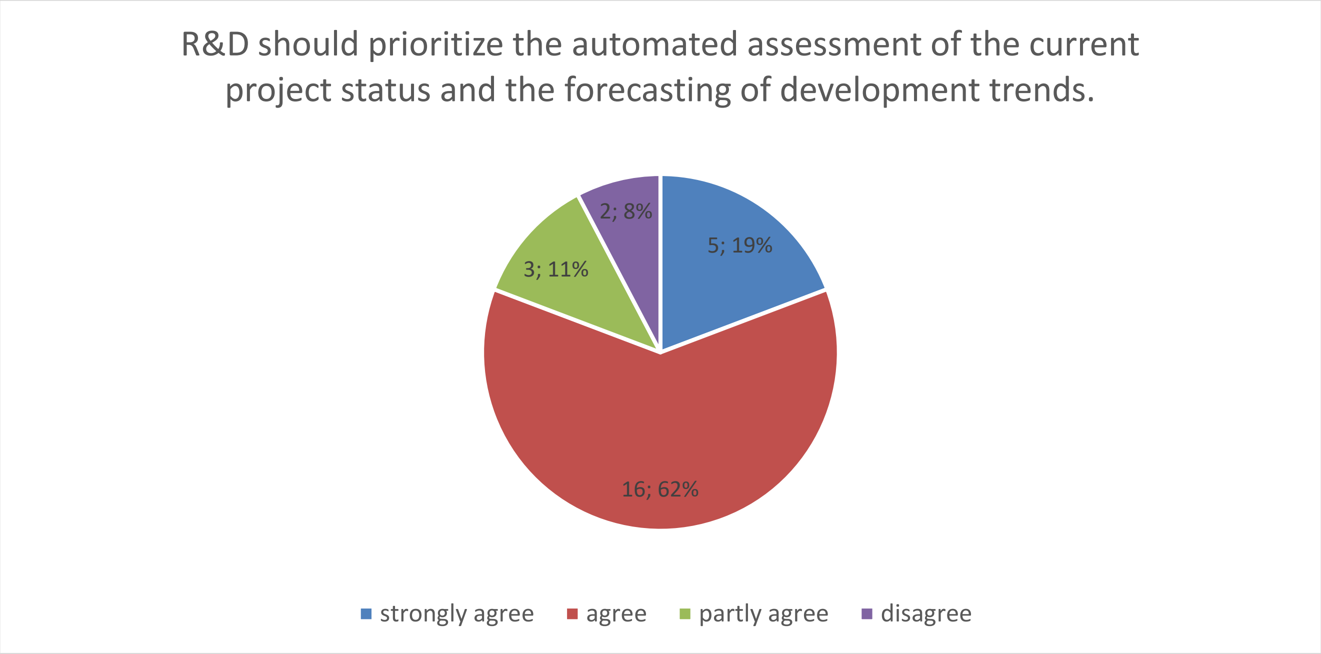

Figure 8: Distribution of responses to Question 1

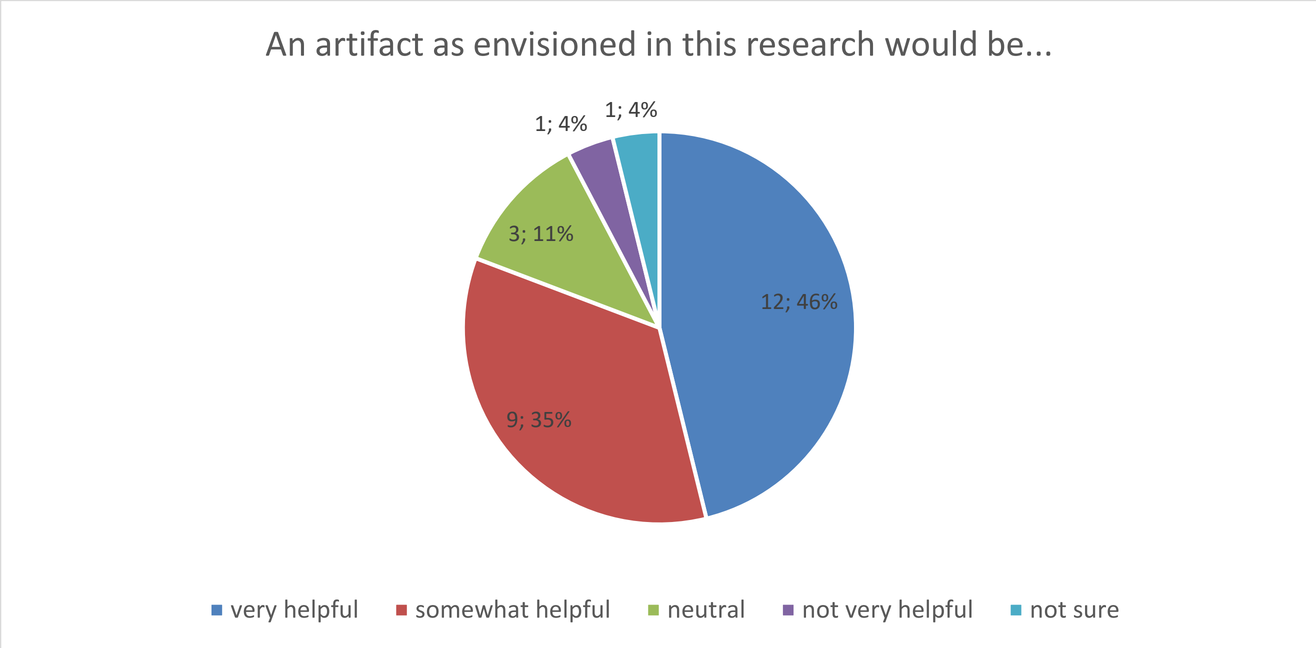

Figure 9: Distribution of responses to Question 2

7 Conclusion

System Dynamics has proven to be an ideal approach for modeling the assessment and decision-making processes in construction project management. The method aligns seamlessly with the general project control cycle, which involves analyzing the gap between the desired and actual states, making decisions to adjust the actual state, measure the actual state and subsequently re-assessing the gap. The practical issues addressed by the proposed Management Information System (MIS) have shown significant relevance to practitioners, as confirmed by the initial field survey results.

The next step is to collaborate with practitioners to develop a comprehensive list of functional requirements. This will guide the development of the artifact and serve as a basis for assessing its quality. Simultaneously, the decision-making process in construction project management needs to be modeled as a quantitative System Dynamics model. This will also involve practitioners to ensure practical relevance.

A third parallel track involves applying control theory to design a feedback controller. This controller will help determine the necessary control measures for our dynamic system to achieve the desired outcomes. Initially, this can be done by leveraging existing project management models and synthetic project data.

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