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A COGNITIVE REVIEW FOR IMPROVING THE COLLABORATION BETWEEN BIM AND LEAN EXPERTS

Soudabeh Davoudabadi [1], Barbara Pedo[2], Algan Tezel[3], and Lauri Koskela[4]

ABSTRACT

Collaboration between Lean Construction and BIM teams is a key factor in exploiting the synergies between Lean and BIM. Although various studies have underlined the importance of team cognition and Team Mental Models (TMM) in the success or failure of collaboration amongst teams, those concepts have not been sufficiently explored from a Lean/BIM perspective. Therefore, this study attempts to introduce the concept of TMM to the Lean-BIM domain by conducting a cognitive review of the Lean-BIM joint implementation at an engineering design firm in the UK with the principal aim of developing a set of suggestions to improve the collaboration between BIM and Lean experts. To collect data, this study used a mixed research approach including secondary research, a case study and semi-structured interviews. Data analysis was conducted through Thematic Analysis to find the main barriers hindering an effective Lean-BIM joint implementation. Findings also suggest that improving the components of TMM can result in an improved Lean-BIM joint implementation. A set of recommendations for Lean and BIM teams' collaboration is also given in the paper.

KEYWORDS

Design, team mental models, team cognition, BIM and Lean collaboration, BIM and Lean synergy.

INTRODUCTION

The importance of effective interaction, teamwork, and collaboration between teams to achieve project objectives is evident as project delivery involves different trades and stakeholders (Dave et al., 2013; Zhang et al., 2018). Furthermore, due to the complexity of teamwork, identifying the cognitive structures (mental models) of team members through which they organise information about team functioning is crucial (Langan-Fox et al., 2004). Effective team functioning is tied to the existence of a Team Mental Model (TMM) among colleagues in a project (Langan-Fox et al., 2000).

[1] Master Student, Department of Architecture and 3D Design, University of Huddersfield, UK U2070281@unimail.hud.ac.uk, orcid.org/0000-0001-5350-5166

[2] PhD Student and KTP Associate, Department of Architecture and 3D Design, University of Huddersfield, UK, b.pedo@hud.ac.uk, orcid.org/0000-0002-6520-0981

[3] Lecturer, Department of Civil Engineering, Aston University, UK, a.tezel@aston.ac.uk, orcid.org/0000-0003-3903-6126

[4] Professor, Department of Architecture and 3D Design, University of Huddersfield, UK, l.koskela@hud.ac.uk, orcid.org/0000-0003-4449- 2281

According to Eynon (2016, p. 31), “Building information modelling (BIM) is the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its life cycle, from earliest conception to demolition”; whereas Lean construction (LC) is an effort to apply lean principals originated from Toyota Production System (TPS) to construction. LC aims at managing the construction processes with minimum cost, maximum value and in compliance with the customers’ requirements (Enshassi & Elsiah, 2019). Although BIM traits and LC principles are compatible (Zhang et al., 2018) and have been implemented jointly recently resulting in important positive synergies, due to various barriers, the construction industry has not used this opportunity to achieve the ultimate synergy between them, yet.

Mental model is described as “mechanisms whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states.” (Keasey Edinger, 2012, p. 21). Team Mental Model (TMM), however, transcends the individual mental models and analyses the shared realisation of a common subject among team members. Badke-Schaub et al. (2007, p.8) argued that “TMM does not only refer to multiple levels or sets of shared knowledge or just to an aggregate of the individual mental models but also to a synergistic functional aggregation of the teams mental functioning representing similarity, overlap, and complementarity”. Thus, it plays an effective role in communication and coordination amongst teams’ members and their performances.

Considering the benefits of the Lean-BIM joint implementation for the construction industry, improving it is required. Furthermore, Lean and BIM approaches are people- and process-oriented (Dave et al., 2013) and as can be realized from the literature, TMM can be considered instrumental for discovering the mental models associated with Lean and BIM teams. Therefore, identifying the Lean team’s and BIM team’s TMMs is expected to contribute to dissolving the barriers at team level, which are the key obstacles to enhancing the Lean-BIM joint implementation, and leading them to improve their collaboration, accordingly. This research has been conducted to address the gap in the literature on the role of team cognition in optimising the collaboration between BIM and Lean teams. This is done through studying the Lean and BIM team’s mental models at a case company in the UK from a TMMs perspective. Although the Lean and BIM synergy has been extensively discussed in the literature, beyond project management level, their integration at company and team level has rarely been discussed (Zhang et al., 2018; Tezel et al., 2020).

The primary aim of this study is to develop a set of suggestions to help enhance the collaboration between Lean teams and BIM teams, and support the Lean-BIM joint implementation in an engineering company. This investigation focuses on answering three main research questions:

- **Q1.** What are the main barriers affiliated with TMM (Task, Team, Team process and Goal knowledge), hindering the Lean-BIM joint implementation in an engineering company?
- **Q2.** How do the components of TMM influence the Lean-BIM joint implementation in an engineering company?
- **Q3.** What mechanisms can be suggested to address those TMMs which cause barriers for an effective collaboration between Lean team’s and BIM team’s members to improve the Lean-BIM joint implementation?

This paper is structured as follows. After a literature review on Lean-BIM collaboration and TMM, the research method of the study is presented. The data analysis is followed by the main findings. The paper concludes with a discussion and key recommendations.

LEAN-BIM COLLABORATION

BIM and Lean, as two main concepts for the modern construction project management are integral approaches, even though they are different (Sacks et al., 2010). Multiple studies have been conducted to date, examining the interrelations between BIM and LC (Evans & Farrell, 2021). For example, Sacks et al. (2009) investigated the ways of adopting BIM to fulfil the needs of effective information flow and transparency for implementing Lean. By juxtaposing BIM features with LC principles, Sacks et al. (2010) identified 52 positive interactions (synergies) out of 56 interactions between Lean and BIM, such as increased flexibility, improved collaboration in design and construction, decreased variability and cycle times.

Studies conducted by Dave et al. (2013) and Zhang et al. (2018) further emphasized the benefits of the Lean-BIM synergy in terms of completing construction projects on time and budget, reducing wastes and rework, and improving quality. Therefore, to acquire the most advantage of Lean-BIM synergy, BIM and LC are necessary to be implemented fully integrally (Evans & Farrell, 2021).

Nevertheless, various barriers to the Lean-BIM joint implementation were identified by researchers. For example, lack of collaboration and coordination, and lack of transparency (Evans & Farrell, 2021; Zhang et al., 2018) as well as various levels of readiness for accepting the changes in conventional methods (Evans & Farrell, 2021; Olawumi & Chan, 2018) were suggested to date.

To achieve most benefits from Lean-BIM synergy, the dynamics of this collaboration should be focused on and explored more (Azhar et al., 2012). However, the literature review shows that most of the research to date on Lean and BIM interaction is concerned with either exploring the mutual synergies between Lean and BIM or demonstrating how BIM facilitates Lean or vice versa at a project level. Yet, to the best of the researchers' knowledge no study has been conducted to date which underpins the role of TMM in the Lean-BIM joint implementation. Therefore, this study adopts the TMM concept to explore the collaboration dynamics between Lean and BIM teams and contribute to enhancing the collaboration between them.

TEAM MENTAL MODEL

According to Langan-Fox et al. (2000) and Badke-Schaub et al. (2007), most early research on mental models merely discussed individuals' mental models. This concept can help in describing the behaviour, knowledge, and performance of individuals and teams (Casakin & Badke-Schaub, 2017). The idea of Team Mental Model (TMM), however, was introduced initially in 1990, by Cannon-Bowers, Salas, and Converse, as a way to improve both realisation and studying the communication and coordination among team members through observing the operation of effective teams in various uncertain and complex circumstances (McNeese et al., 2014). Klimoski and Mohammed (1994) described TMM as knowledge or belief structures that are shared by the members of a team, which enable them to form accurate explanations and expectations about the tasks. TMM also enables team members to coordinate their actions and adapt their behaviours to the demands of the tasks of the project and of their colleagues (Bianchi et al., 2015; Badke-Schaub et al., 2007). Langan-Fox et al. (2000) argued that in order to operate and interact successfully in a team, the team members are required to adopt a similar way to understand, encode, store and retrieve information.

There are various areas of knowledge specified in TMM, which are prerequisites for working in a team (Wise et al., 2021; Burtscher & Manser, 2012). Wise et al. (2021) described the four major components of TMM as follows:

- **Task Knowledge** refers to the knowledge and skills required for performing the team members' duties.
- **Team Knowledge** refers to the team members' understanding of each role's duties, in addition to the specific skills of individual team members.
- **Team Process Knowledge** refers to the realisation of the needed procedures and behaviours for interacting and coordinating with other colleagues in projects.
- **Goal Knowledge** refers to the team members' understanding of colleagues' shared goals and objectives.

Many have reported the benefits associated with TMM in improving team performance and creating an effective coordination among team members. Klimoski and Mohammed (1994) and Banks and Millward (2007) stated that those teams whose members have shared models in both task work and teamwork perform more effectively through enhanced coordination, because the team members understand and predict the other members' needs and actions better (Lingard et al., 2015). Moreover, Langan-Fox et al. (2004) summarized the potential benefits of the relationship between TMMs and performance, some of which include more effective communication by less communication actions through using shared models such as common language (Langan-Fox, 2001), more prompt mutual learning, and improving the allocation of responsibilities by considering the strengths and weaknesses of team members (Langan-Fox et al., 2004). Van den Bossche (2006) drew the attention to the close relationship between cognition and interaction and then, Ybarra, et al. (2008) described that these two concepts have direct influence on each other (McNeese et al., 2014). Nevertheless, Houghton et al. (2000) proposed that TMMs may cause "groupthink" biases, which is defined as a possible disadvantage that groups may experience when conformity pressure leads to faulty decision-making (Janis, 1982) and can be seen in a wide range of groups working together in various fields (Rose, 2011).

Literature review found only a few studies exploring TMMs in the construction area. Fry (2004) focused on coordinating and describing various design terms through creation of an appropriate mental model. Badke-Schaub et al. (2007) investigated the relation of the theoretical concepts of mental models and design teams and Goldschmidt (2007) studied design teams' Mental Models. Casakin and Badke-Schaub (2017) explored the sharedness of TMMs in design-related interaction between architects and clients. Bridging two domains of construction management and cognitive science with the focus on BIM and Lean, TMMs can lead to the improvement of the Lean-BIM joint implementation and integration.

RESEARCH METHOD

Case study is the research method of the study. The Lean and BIM teams at an engineering design company in the UK are units of analysis. Case studies are suitable for studying phenomena in their real-life contexts where researchers have no control (Yin, 2003). The company is a large, international engineering design and consultancy company delivering solutions for natural and built assets in over 70 countries, however, the study was focused on the UK branch. They are considered advanced by their supply chain in terms of their Lean and BIM implementations.

To explore the Lean-BIM interfaces at the company, secondary data including company records, meeting notes, and documents related to the KTP project were reviewed initially. As the result, it was realized that this company has been involved in the implementation of some Lean and BIM initiatives approximately six years and more than twenty years, respectively. However, the Lean and BIM integrated implementation within the company was fragmented, lacked co-ordination and was still immature. The company is also collaborating in a Lean and BIM integration focused Knowledge Transfer Partnership (KTP), a government sponsored knowledge exchange scheme between universities and companies in the UK.

Alongside reviewing the company documents, five practitioners from the company's Lean team and five practitioners from the BIM team were interviewed using semi-structured interviews (10 interviews in total) and the cognitive interviewing technique in order to investigate their viewpoints, mindsets and various components of TMMs. The semi-structured cognitive interviewing technique was selected as it helps researchers to achieve in-depth and rich information regarding a specific domain through eliciting interviewees' experiences and thoughts (Turner III, 2010). Analysis was done by identifying and grouping similar themes and approaches through thematic analysis, to be described below, and the findings were shared with and validated by the company.

Firstly, the questions of interviews were developed so that participants were allowed to reply to the questions in their own terms and convey their views and opinions regarding Lean and BIM experts' work mentalities, advantages and outcomes of the Lean-BIM joint implementation identified by them in their affiliated projects. Four main components of TMMs (Task, Team, Team process and Goal knowledge) were investigated, as well. Then, the interview meetings were conducted through Microsoft Teams and the transcripts were recorded. Subsequently, collected data was analysed using the thematic analysis technique. This method is used to identify and represent patterns (themes) within a qualitative data set, enabling researchers to flexibly organise and describe the data with rich detail (Braun & Clarke, 2006). Six consecutive phases of thematic analysis, as suggested by Braun and Clarke (2006), were followed:

- **Familiarising with the collected data.** The initial ideas were derived from the transcriptions of Lean and BIM participants' responses and sorted into two categories comprising BIM and Lean.
- **Generating initial codes.** The similar ideas extracted from the raw data were classified in the shared categories, and then interesting features of the data which could lead the research to the TMMs of the participants were systematically coded.
- **Searching for themes among the data.** Coded data was analysed to identify those codes which could be combined to create an overarching theme. Then, the created themes were compared, and main themes and sub-themes were formed.
- **Reviewing themes.** The created themes were reviewed to decide whether they should be considered as a proper theme, should be converted into separate themes, or should be merged into a single theme.
- **Defining and naming themes.** To find out the essence of each theme and to identify the specific aspect of data covered by an individual theme, they were defined and named.

- **Producing the report.** The report of analysis was written to deliver a succinct, clear, logical summary of the story of data.

FINDINGS AND DISCUSSION

Key findings corresponding to the research questions Q1 and Q2 were categorized into two main groups affiliated with the Lean-BIM joint implementation barriers and TMM's four components as follows.

BARRIERS

Barrier 1. Lack of Motivation and Intention towards Collaboration

This barrier stems from two main reasons: (i) lack of readiness for accepting changes in the conventional methods as well as (ii) lack of awareness about the Lean-BIM joint implementation advantages, so the teams do not believe it is worth prioritising and dedicating time to it. These main reasons cause a lack of intention on the part of the experts, particularly in the BIM experts, for an effective collaboration.

Barrier 2. Different Work Mentalities

The way through which the BIM and Lean experts understand, encode, store and retrieve information is different. BIM and Lean experts work in a common data environment, set up by BIM experts at the outset of the project. BIM experts implement considerable improvements. However, unlike the Lean experts, they do not recognise these improvements as Lean improvements, they do not record and store the information affiliated with the benefits of them, and also, they do not implement them in a structured way. Following differences between Lean and BIM experts cause their distinct work mentalities, which may ultimately hinder improving the Lean-BIM joint implementation:

- Using different terminologies by BIM and Lean experts is one of the factors causing them to understand the work issues differently.
- BIM and Lean teams' different attitudes, perspectives, and expected outcomes cause them to encode, store and retrieve information differently. BIM experts mostly have a long-term vision to the projects, leading them to produce a product which can solve the problems for both current and future projects, whereas Lean experts mostly focus on current tasks, collaborative planning and tracking the current progresses.
- BIM and Lean teams' various priorities influence on how they encode and store the data. BIM experts tend to focus merely on delivering their ongoing tasks, while Lean experts concentrate on all the objectives of the projects. Lean experts look for efficiency and streamlining, while BIM experts look for quality of design.
- They have different tasks and use different strategies, tools, and techniques to fulfil their tasks, impacting the methods they encode, store and retrieve the required information.

Barrier 3. Lack of a Common Approach

A confusion among the experts of either field could be observed in terms of the required strategy for accomplishing their tasks in a collaborative context, as participants stated that they are not aware of how they should function more collaboratively while fulfilling their tasks. This is due to the lack of a designated collaboration strategy, introducing a structural and organisational gap. Parallelly this creates an opportunity for the company's decision makers to establish an innovative collaborative approach which will support providing the teams with an appropriate guideline.

Barrier 4. Groupthink Biases

Biases of "groupthink" were observed in the participants, so that either team's experts tended to expect that most of the actions and measures which are required to be carried out for improving the Lean-BIM joint implementation should be taken by the other team.

MAIN TMM COMPONENTS

Task Knowledge

The structure of this component is composed of two main concepts namely "knowledge" and "skill". The former can be improved through training, while the latter cannot merely be developed in a similar way, but through repeated practical application of the knowledge obtained through training. Therefore, "skill" and accordingly "task knowledge" are not flexible concepts for change in short term, as it takes time to improve individuals' skills.

Team Knowledge

This is the main component of TMM to address the waste of "lack of clarity in the transfer of information between disciplines" as it can contribute to increasing the transparency within team procedures and lead to an improved BIM-Lean collaboration.

Team Process Knowledge

This is the main component of TMM to address the wastes of "delay, waiting and rework". Thus, enhancing this component will cause increased efficiency. Not only time-related issues, but also other key concepts such as communication, personal traits, terminology, and the method of conducting meetings influence constructing team processes and therefore, play significant roles either in generating the aforementioned wastes or removing them.

Goal Knowledge

This is the main component of TMM to improve the efficiency. Sharing goals and objectives or having different ones is one of the main factors in either improving or hindering the collaboration within teams. Teams sharing goals will feel more obliged to interact and work together, increasing the level of trust that can be developed through collaborative interactions (Badke-Schaub et al., 2007).

RECOMMENDATIONS

It is worth mentioning that altering people's mental models occurs in time. In other words, it will be a long-term transition period to move toward conceptual and structural changes (Langfield-Smith & Wirth, 1992). In this regard, the following recommendations are proposed.

MOTIVATION

Being aware of the benefits of BIM-Lean collaboration in the outcomes of a project is not motivating enough for each individual expert, as stated by the participants. Therefore, they should become more aware of the direct benefits of the Lean-BIM joint implementation on streamlining their own tasks, and the specific benefits and outcomes that can be achieved through this synergy for them. For instance, they can be trained on the topic of Lean-BIM synergy so that they will realise that it can eventually help them improve their work/life balance and mental health.

PERFORMANCE-BASED REWARD SYSTEM THEORY

This theory should be considered by the managers and champions of the innovative mechanisms of Lean-BIM at the company. It asserts that employees will be motivated to undertake a task if they think a particular reward will be forthcoming (Vroom & Gimeno, 2007; Kerr & Slocum, 2005). There is currently no certain performance-based reward system defined for the Lean and BIM collaboration at the company.

TAKING COGNITIVE CONSULTATION

Cognitive consultation can help in maximising the team members' efficiency through optimizing their mental health as well as resolving the mental barriers hindering them to communicate and collaborate with others effectively. Individual and group cognitive consultations should be planned to focus on improving the collaborative perspectives and functions within BIM team's and Lean team's members. This also can lead them to approach the Lean-BIM joint implementations further. This aim can be achieved through taking specific consultations to reduce the resistance that team members have against changing the traditional methods and strategies, to reduce workplace stress, to improve time management skills, and to enhance communication skills. Therefore, taking consultation and professional advice from cognition experts will be beneficial for planning, implementing, and sustaining the Lean-BIM joint implementation from the viewpoint of cognition.

INPUTTING LEAN INTO BIM

Assigning Lean experts to BIM teams to train them about the Lean principles and techniques, and to guide them to implement Lean into the BIM processes at the company will be useful. This will help BIM teams to better understand the benefits, opportunities and mechanisms of Lean into BIM, encouraging the joint implementation as a standard practice in the sector.

TRAINING ON LEAN-BIM JOINT IMPLEMENTATION

A set of meetings and workshops should be planned and delivered on a regular basis, aiming to improve the awareness of the experts of either field on the outcomes of Lean-BIM for individuals' work, collaboration-related skills such as communication skills and punctuality, as well as the way through which the collaborative tasks should be implemented. Experts should be also trained and convinced that this collaboration can help them with time management and removing the wastes related to time; otherwise, they may look at this idea as an extra time-consuming task, exerting more pressure and responsibilities onto them.

Colleagues working together closely play a significant role on each other's collaborative approach and TMM. This is the case particularly for the juniors who are in their initial steps of working in the company. The juniors should be trained on the importance of Lean-BIM joint implementations and the standards of implementing it early in their careers.

PRESENTING THE NEW ROLE OF LEAN-BIM EXPERT

Assigning or nurturing Lean-BIM experts, who are knowledgeable and experienced in both fields of Lean and BIM, in order to function as facilitators to drive the concept of a Lean-BIM joint implementation within the company. It is worth mentioning that although the company has already this third group amongst their practitioners, they are categorized in either BIM or Lean team and thus, they are assigned to either Lean or BIM tasks likewise the other practitioners who are experienced in merely one of the Lean or BIM fields. In other words, they are not categorized as the third group or role which can be named as "practitioner with both BIM and Lean knowledge and skills" to undertake certain tasks affiliated with the Lean-BIM joint implementation.

DEVELOPING APPROPRIATE GUIDELINES

Sufficient consideration by the company's decision makers is required to provide the BIM and Lean experts at the company with appropriate collaboration guidelines for them to work "on the same page".

IMPROVING COMMUNICATION AND VIRTUAL MEETINGS

Multiple improvement measures affiliated with communication amongst experts as well as virtual meetings were suggested, which can be planned and implemented.

Suggestions for improving communication are related to three key areas: training, terminology, and managing communication. Training recommendations can be described as: (i) holding workshops for familiarizing teams with Lean techniques and BIM processes and tools; (ii) training about communications skills, so that experts can be open and effective in listening and communicating; (iii) creating awareness modules on teams' terminology. The terminology aspect includes: (i) increasing the clarity of roles and responsibilities; (ii) setting up clear communication protocols and guidelines; (iii) setting up dictionaries for defining abbreviations and unique terminologies. Finally, managing communication issues are related to the skills required for the Lean practitioner (e.g., extroverted) to manage the communication among project members. Furthermore, the suggestions for improving communication through virtual meetings can be described as: (i) training; (ii) attendees should be advised to set their cameras on; (iii) applying lean principles to remove the waste related to the confusion caused by multiple platforms; (iv) setting a structured agenda for sensible short meetings with a break time; (v) identifying and using appropriate platforms and technologies, for which training is essential.

SUSTAINING THE NEW COLLABORATIVE APPROACH

To sustain the implementation of the proposed recommendations, it should be monitored and checked through using lean techniques such as "plan, do, check, act" and 5S.

CONCLUSION

Although multiple studies have highlighted the importance of teams' cognition as one of the of most significant factors affecting the success or failure of teams, cognitive studies and functions have not been sufficiently prioritised in construction research and practice to date. To achieve the Lean and BIM benefits at the project level, their effective integration at the company and team level is essential.

This research merged the areas of cognition and construction to investigate and tackle the mental barriers hindering an effective Lean-BIM joint implementation. Using a set of research techniques, the TMMs of BIM and Lean experts at an engineering design company in the UK were explored and analysed. Findings demonstrated that different work mentalities, lack of motivation and knowledge, and groupthink bias have been the main barriers to their collaboration.

The results and findings can contribute to generating knowledge in the domains of Lean and BIM teams' TMMs, and Lean-BIM integration and joint implementation. They also can contribute to addressing the identified wastes and barriers to the Lean-BIM joint implementation in the context of the company, and to increasing the efficiency in mid- and long-term through the reduction of errors, which occur due to the lack of communication and collaboration between the Lean and BIM experts. Eventually, they may contribute to getting the TMMs of the Lean and BIM experts closer and achieving encouraging outcomes for all stakeholders of the company, including BIM and Lean teams, clients, and contractors.

Based on the results and findings, prioritising the cognitive studies and functions such as applying proposed recommendations affiliated with mental models (i.e. improving the practitioners' motivation, taking cognitive consultation, etc.) should be an important concern of the management at the company. Moreover, alongside the prior research, the findings of the current research imply that the “groupthink bias” creates a serious obstacle for the collaboration between different teams; this should be further studied.

As explained above, the findings of this research can contribute to enhancing the efficiency in the company by introducing an innovative approach of Lean-BIM interface based on developing the third role of the “practitioner with both BIM and Lean knowledge and skills”. This research considers the aforementioned role as a facilitator to support the practical measures proposed to the company in order to enhance the Lean-BIM joint implementation important. This requires exploring the necessary characteristics of the merged role (Lean-BIM practitioner) in future studies.

Furthermore, as stated in this paper, BIM team’s and Lean teams’ members may function further collaboratively provided that they become more aware of the direct benefits and outcomes of the Lean-BIM joint implementation for them. This introduces a topic to be considered by researchers in future studies.

The analysis presented in this paper was limited to a single case company. Expanding this study to more companies will be useful for generalizability. Moreover, the lack of awareness of the participants about the notion of TMM and its terminology might have affected the accuracy of the responses and analyses.

The dynamics between Lean and BIM teams in organisations is also very much open to study and analysis from a behavioural management perspective (e.g. the cognitive dissonance theory, reinforcement strategies, antecedent/behavioural approaches, organizational forgetting), which could be exploited in future research.

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