ADOPTION OF DIGITAL TECHNOLOGIES FOR ASSET MANAGEMENT IN CONSTRUCTION PROJECTS

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Gustavo Attencia, MSC,
Centro Universitário FEI;
gustavoattencia@yahoo.com.br

Claudia Mattos, Professor,
Centro Universitáro FEI;
cmattos@fei.edu.br

SUMMARY: *Smart asset management can provide a framework for validating and improving asset performance, as well as collecting and incorporating reliable asset information into the decision-making process. In this context, this study analyzes the adoption of technology in the management of intelligent assets through multiple case studies, the technologies used, and the factors that possibly affect the level of technology adoption in asset management and a new method for operating. Technology-Organization-Environment framework and Technology Acceptance Model were used to analyze the main factors influencing technology adoption in intelligent asset management. The contribution of the study lies in the integration of asset management concepts and technology adoption. This integration allows structuring a theoretical framework for technology adoption by identifying the adoption factors in each phase of the asset management cycle in construction projects.*

KEYWORDS: *Technology adoption; Asset management; Smart asset management; Digital technology.*

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1. INTRODUCTION

Companies adopt different technologies to gain competitive advantage. Technology capabilities play an important role in risk analysis and decision-making while helping companies in the asset management (AM) task. Technological developments in the field of Internet of Things (IoT), for example, ensure the supply of relevant information to stakeholders, and knowing how to process and analyze data to make decisions defines the competitive difference (Kinnunen et al., 2017). Nel and Jooste (2016) reinforced this approach and indicated in their study that the technological level of equipment and AM allows companies to leverage the results.

Companies find it challenging to adopt these technologies in AM. Existing tools ease decision making but impose big challenges for integrating data and do not support partial or total autonomous decision making, which also demonstrates the need for technological development (Artikis et al., 2014, Le and Jeong, 2016). Additionally, the adoption of new technology implies a transition period that requires new skills and associated training, which can hinder the implementation of digitized systems. It is essential to highlight the benefits of adopting technologies (Rahman et al., 2016).

Love et al. (2016) discussed the need for studies to determine the best method for including information systems in AM, while focusing on the aspects related to diffusion and adoption of technology. Love and Matthews (2019, 2020) reinforced that intelligent AM is a new concept and needs in-depth study and analysis of its implementation. Han et al. (2018) reported that companies use inefficient methods rather than technology to effectively manage their assets. Morever, the use of technology in permanent organizations and its use in temporary organizations is rarely distinguished, for example, in construction projects (Jacobsson; Linderoth, 2010). In contrast to other industries, the civil construction industry is characterized by dynamic projects involving factors such as extensive labor and changes in scope during its implementation. Moreover, during the project's lifecycle, several documents with relevant data are produced and exchanged. These data are presented in different formats and stored in different databases (DBs) and applications (even on paper). Therefore, the adoption of new technologies is imperative and challenging because the mere presence of technology will not guarantee better project results, but its implementation. (Martínez-Rojas; Marín; Vila, 2016).

Based on the research gaps, the following research question guided the development of this study:

What are the factors related to the adoption of technology identified for AM in construction projects?

Accordingly, this study analyzes the adoption of digital technologies related to AM through multiple case studies and identifies the technologies used and the factors that may affect the level of technology adoption.

To address the research problem, this study uses the Technology-Organization-Environment (TOE) framework proposed by Tornatzky and Fleischer (1990) based on the technological, organizational, and environmental factors, along with other theories such as the Technology acceptance model (TAM) model developed by Davis (1986, 1989) and the TAM2 model enhanced by Venkatesh and Davis (2000, 2003, 2012).

2. LITERATURE REVIEW

AM is defined as the set of activities associated with business objectives that seek to identify the required assets, provision of logistics support systems and asset maintenance, and disposal or renewal of assets to effectively and efficiently meet the desired goal (Hastings, 2010). Rogage and Greenwood (2020) mentioned the importance of the Operation and Maintenance phases as crucial for optimizing costs and asset efficiency.

From a user's perspective, the asset's lifecycle can be indicated as the succession of five main phases (Ouertani; Kumar; Mcfarlane, 2008):

- Acquisition, which comprises all activities involved in the technical and financial analysis, justification and planning for the acquisition of new assets;
- Commissioning, which represents the activities associated with the installation, testing, and commissioning of assets;
- Operation, which defines how the asset is used and applied to achieve the objectives;
- Maintenance, where all activities involved in the conservation and most effective maintenance of asset availability, longevity, quality, and performance;
- Demobilization comprises all activities in decommissioning, replacement definition, remanufacturing, and sale. All phases of the life cycle are important for managing information for action in the context of AM.

2.1 Digital technologies for AM

As discussed by Martínez et al. (2018), digital technologies are no longer considered simple tools but are active actors in value creation. Digital technologies can be considered as actors driving the new value proposition (Herterich, Uebernickel, and Brenner, 2015). Studies have indicated new value creation opportunities around digitization, such as automation of manufacturing systems, market intelligence, risk mitigation, and service innovation (Rymaszewska, Helo, Gunasekaran, 2017). Among the AM technologies, telemetry (Ouertani, Parlikad, and Mcfarlane, 2008) is a technology that remotely monitors the parameters of any system; this technology is popular in fleet management.

Recently, high-resolution digital cameras, large data storage capacities, and the availability of internet connections have enabled capturing and transmitting of asset performance information on a massive scale (Golparvar-Fard et al., 2015).

The IoT has enabled communication of asset information over the internet through embedded sensors that enable real-time diagnosis and decision-making (Ashton, 2009). With the development of sensors, IoT, and data network, several predictive variables in AM have been monitored online, thus generating key information for their maintenance. The so-called e-maintenance facilitates integration of technologies, such as electronic monitoring, diagnostics, and real-time forecasting, which enables real-time remote control and evaluation of systems (Macchi et al., 2014). IoT can enable more effective and efficient AM through data analysis, planning, and effective actions according to user needs (Archetti; Giordani; Candelieri, 2015).

Brous, Herder, and Janssen (2020) indicated that IoT can benefit AM organizations by providing quality data and generating the information necessary for right and timely decision-making by asset managers. Brous et al (2019) demonstrated that new technologies such as IoT enable data generation that help automate the AM process, yet the level of adoption of these technologies remains low.

Big data development is characterized by its growing technological capacity to capture, aggregate, and process high volumes of varied data at high speed. Technologies such as data mining, learning machine, and statistical tools have been used for a long time, but the amount and types of data that must be processed and analyzed differentiate these technologies from the concept of big data. The main purpose of data mining and learning machine algorithms is to transform data into knowledge and find hidden patterns (Agnellutti, 2014).

In addition to emerging technologies, simulation is characterized as a relevant tool for predicting the processes occurring in the physical world (Negri, Fumagalli, and Macchi, 2017). Digitization, or digital replication (also called "digital twin") plays an important role in AM, as it enables the simulation of the asset's life cycle to analyze the life stages and their interference, thus facilitating decision making (Macchi et al., 2018). Smart connected objects, which are part of the Digital Twin, allow manufacturers to collect and explore data by developing new services and improving customer relationships.

Autonomous transportation systems, which use high-precision GPS navigation, millimeter-wave radar, and fiber optics gyro technology to control unmanned equipment, represent a major technological breakthrough, and companies should be prepared to assimilate this technology (Sepasgozar and Davis, 2018).

2.2 Adoption of digital technology

Oliveira and Martins (2011) claimed that the adoption of new technologies and its critical factors can be understood is through the models of adoption of information technologies in organizations. Among the theories used in the area of information systems, we highlight the following used for adoption of information technology (IT):

- *Technology, organization, and environment* (TOE) (Tornatzky and do Fleischer, 1990);
- *Technology acceptance model* (TAM) (Davis 1989; Davis et al. 1989);
- *Technology acceptance model* 2 (TAM2) (Venkatesh and Davis 2000).

Tornatzky and do Fleischer (1990) proposed a framework called TOE, considered by most studies on the adoption of technological innovation as the most appropriate structure to understand the adoption of IT in an organizational context. The TOE framework explains that three different contexts influence the decisions to adopt new technologies, namely, technological, organizational, and the environment. The TOE framework, as originally presented and later adapted to IT adoption studies, can be used to study the adoption and assimilation of different types of IT innovation.

The TAM theory states that an individual's behavioral intention to use a system is determined by two perceptions, namely, ease of use and usefulness, both fully measure the effects of external variables, such as system characteristics, development process, and training, in the intention to use (DAVIS, 1989).

The TOE framework has been examined across different subjects and contexts to prove its theoretical strength, empirical support, and usefulness in adopting and implementing various forms of innovations (Aboelmaged, 2014).

Organizations are currently experimenting with new data sources, and IoT is expected to offer significant added value for decision making on AM. The adoption of the IoT requires proper data management to ensure compliance with laws and regulations. Data governance must ensure that IoT can provide reliable data for decision making in AM (BROUS et al., 2017). Data analysis can be understood as a continuous series in which data are transformed into information and later into knowledge (Mandinach, 2012). The study of Brynjolfsson, Hitt and Kim (2011) has conclusively demonstrated that data-based decision-making represents increased productivity and greater return on assets.

Studies on the adoption and use of Information and Communication Technology (ICT) have limited distinction between the use of technology in permanent organizations and its use in temporary organizations, for example, in construction projects (Jacobsson; Linderoth, 2010).

Jacobsson and Linderoth (2010) highlighted this distinction to understand how the interaction between contextual elements, structures, actors, and technology itself influence the adoption and use of technology in a construction project. They highlighted that in the absence of immediate perception of the benefits from adoption and use, the technology will not be assimilated.

Brous, Janssen, and Herder (2015, 2017) demonstrated th at AM requires a change in culture to adopt new technologies. Decision-making processes are changed to handle real-time data from assets, while managers should adapt and develop new skills and abilities to interpret the data.

Sepasgozar and Davis (2018) examined the possible methodologies for adopting digital technology in the construction sector projects and investigated how customers make decisions to adopt the technology and how suppliers support them in this decision process. There are significant and clear gaps in understanding the adoption of building technology at the organizational level, particularly concerning supplier involvement in the process. This study examined how the industry follows specific decision-making processes linked to the preadoption process for research and the postadoption process for implementation.

This study evaluates the adoption of technology in AM in the context of projects, specifically large complex infrastructure-related construction projects, classified as complex because of the size and amount of interference affecting their outcome (HU et al., 2015). Sankaran and O'Brien (2018) indicated that complex projects with larger budgets can absorb implementation costs and leverage the opportunities offered by technologies. Smaller projects, however, may face resource constraints to deploy technologies.

3. METHODS

Accordingly, this study develops a multiple case study and an integrative model to analyze the factors that affect the adoption of technology in AM in construction projects, especially those associated with complex projects (Figure 1).

Therefore, the TOE framework model was used to analyze the business context, and the TAM model was used to analyze the context of the individual (Table 1).

Through qualitative analysis and multiple case study method, this study was developed to evaluate the adoption of digital technology in AM. Accordingly, we analyzed four cases included in the environment of large infrastructure projects. To collect information, semistructured interviews were conducted with project managers; documents were analyzed, such as reports, presentations, performance indicators, procedures, and the software that interfaced with the technological tools. WEBQDA software was used to analyze the data obtained from the interviews conducted. WEBQDA is a text, video, audio, and image analysis software that works in a collaborative and distributed web-based environment. The software allows the editing, viewing, interconnecting, and organizing documents.

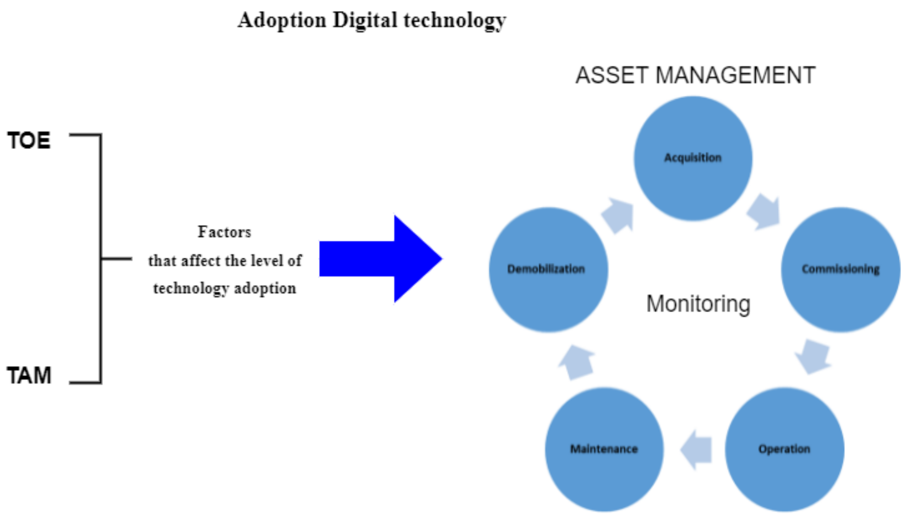

Figure 1: Model Research

Table 1: TOE and TAM Factors

Context	Factors	Authors					
		Davis (1985)	Tornatzky and Fleischer (1990)	Venkatesh and Davis (2000)	Haider, Koronios and Quirchmayr (2006)	Aboelmaged (2014)	Sepasgozar and Davis (2018) [13]
Technology	Relative advantage	x	x	x		x	x
	Compatibility		x			x	
	Complexity	x	x	x	x	x	
	Technological availability		x		x	x	x
	IT infrastructure		x		x	x	x
	Direct perceived benefits	x	x	x	x	x	
	Perceived indirect benefits		x	x	x	x	x
	Perceived risks		x		x	x	x
Organizational	Attitudes toward innovation	x	x	x		x	x
	Financial resources		x		x	x	x
	Organizational size		x			x	x
	Culture information sharing		x			x	
	Learning culture		x			x	
	Top management support		x			x	x
	Knowledge		x			x	x
Environment	Competitive pressure		x		x	x	x
	Environmental uncertainty		x			x	x
	Regulatory support		x		x	x	x
	Business partner readiness		x			x	x
	Support from technology providers		x			x	x
TAM	Perceived ease, utility, and behavioral intention	x		x			

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3.1 Respondents' profile

For broadly analyzing the cases and the data from different perspectives, the interviews were conducted with people who were involved in respective projects in different roles and hierarchical levels. We sought to interview people who were experts in the theme and effectively participated in the project. To enable a larger sample size, we interviewed at least three people in each case study, in which we sought those at different hierarchical levels and with more than 10 years of professional experience (Table 2).

Table 2: Profile of respondents

Project	Respondent	Function	Professional Experience
A	Interviewee 1	Equipment Manager	35 years
	Interviewee 2	Engineer	12 years
	Interviewee 3	Technician	10 years
B	Interviewee 1	Equipment Manager	15 years
	Interviewee 2	Engineer	25 years
	Interviewee 3	Technician	15 years
C	Interviewee 1	Equipment Manager	30 years
	Interviewee 2	Corporate Manager	20 years
	Interviewee 3	Technician	12 years
D	Interviewee 1	Equipment Manager	15 years
	Interviewee 2	Corporate Manager	20 years
	Interviewee 3	Engineer	12 years

Source: authors.

3.2 Case Studies

Four case studies were conducted in construction projects related to the energy infrastructure sector in Brazil. In this section, the designs and technologies described in Table 3 are used.

Table 3: Cases Description

Project	Description	Digital Technologies applied
A	PROJECT A comprises constructing a hydroelectric plant with a generation capacity of approximately 3,568 Megawatts of electricity, which is sufficient for the consumption of over 45 million people.	• Truck Monitoring System; • Machine Monitoring System; • Cellphone Pointing System • Other Technologies (FRID).
B	Project B comprises constructing a 3,750-megawatt hydroelectric power plant, which began construction in 2009 and was completed in 2016. Consisting of a consortium of private companies, it was a large project, with about 20,000 employees at its peak and over 1,200 construction devices.	• Automatic supply control system • Pointing and data collection system: The deployed system has satellite communication, which allows the operation in remote areas without telecommunications infrastructure.
C	PROJECT C: The third case studied uses an infrastructure project in the energy sector as its analysis unit, represented by a hydroelectric plant with a generation capacity of 11,233 megawatts, which started in 2011 and is expected to be completed by 2021. The project's peak production had about 5,000 construction equipment units and over 35,000 workers.	• Tracking off-highway machinery and trucks • Road truck monitoring • Dispatch Control System: through a radio frequency network and satellite positioning system; about 900 devices were monitored and controlled.
D	PROJECT D: The fourth project evaluated also refers to a project for constructing a 350-megawatt hydroelectric power plant, with an investment of around R$ 2 billion; the project started in 2013 and was completed in May 2019.	• Truck Monitoring System; • Electricity Monitoring System • Central Crushing Monitoring.

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4. RESULTS

From the studies conducted, the main factors that support the discussion of integrating digital technology adoption in the asset's lifecycle were summarized. The factors were identified from the TOE and TAM 2 models. As mentioned earlier, the TOE framework is based on the technological, organizational, and environmental dimensions in the context of projects, combined with the TAM 2 framework, which analyzes user acceptance of the technology. The acceptance is characterized as perceived ease of use, perceived utility and behavioral intent, and ability to support the understanding of factors contributing to the adoption of digital technologies and successful implementation. The identified factors that affected technology adoption in the evaluated cases are detailed in Table 4.

Table 4: Adoption Factors

Theoretical Context		Factors	Factors/Cases			
			A	**B**	**C**	**D**
TOE	Technology	Compatibility	x		x	
		Complexity	x	x		
		Technological availability	x	x	x	x
		IT Infrastructure	x	x	x	
		Perceived Direct Benefits	x	x	x	x
		Perceived Indirect Benefits		x	x	x
	Organization	**Attitudes toward innovation**	x	x	x	x
		Financial Resources			x	x
		Organizational Size	**x**	**x**	**x**	**x**
		Learning Culture	x	x	x	
		Top management support	x		x	x
		Knowledge	x			
		Process integration	**x**	**x**	**x**	**x**
	Environment	Competitive pressure			x	
		Environmental uncertainty			x	
		Regulatory support	x			
		Business partner readiness	x	x	x	
		Support from technology providers	**x**	**x**	**x**	**x**
TAM		Perceived ease of use	x	x	x	x
		Perceived usefulness	x	x	x	x
		Behavioral intention	x	x		x

Some factors were evidenced in all evaluated cases, such as technological availability, perceived direct benefits, attitude toward innovation, organizational size, process integration, support from technology providers, and perceived ease of use and perceived utility.

Technological availability: The four projects analyzed used a set of technologies such as GPS tracking, IoT, and advanced analytics. These technologies are embedded in the equipment used in the projects, and one of the adoption factors is directly linked to this technological availability. In addition to the technological resources embedded in the equipment, which improves its performance, asset-related information management plays an important role in risk analysis and decision making. Technological developments in the field of IoT, for example, guarantee information relevant to the stakeholders and how to handle and analyze data to make decisions to gain competitive edge.

Attitude toward innovation: Recently, the construction industry has undergone transformation. The companies are motivated to develop innovation or incorporate innovations seeking to maintain competitiveness and increase creativity to adapt to the new recessive economic scenario in Brazil. The creation, dissemination, sharing, investment in knowledge, and innovation have become important sources of long-term sustainable organizational competitive advantage.

Support from technology providers: According to the environmental context, the trading partner's readiness and the technology providers' support demonstrated its importance mainly in the implementation phase.

An analysis of technology adoption and assets' lifecycle cases showed that the technological tools were only effectively used in the operation and maintenance phases, while minimally in the acquisition and demobilization phases. The initial phase of the project was characterized by low infrastructure and a large number of new employees with less experience, which led to underuse of the technologies. After this phase, the reports based on the interviews indicated that the tools were assimilated more effectively. In the project conclusion phase, where many assets were made available for sale and a small group of assets remained in operation, the technological tools were no longer used. This indicates a conflict with the assimilation of technology, which was motivated by the high cost of maintenance and the fact that the assets were no longer the main activity of the project and represented an activity of secondary relevance, considering the invoicing from the company. According to the literature and the interviews conducted, the relevant factors in each phase of the asset's lifecycle may be correlated.

4.1 Results and Discussion

The variables related to technology adoption were confirmed in the field research. Regarding the discussion based on the TAM 2 model, the cases indicate the importance of understanding human behavior toward acceptance or rejection of technology. The results confirm the mediating role of the variables "perceived ease of use" and "perceived utility" in a complex relationship between system characteristics (external variables) and potential system use. According to Edmondson et al. (2018) and Bouleau et al. (2008), integration has emerged as an important factor for adopting technology. Modern systems must be integrated with larger systems to enable solutions that provide better data control and more effective management. The synergy and integration of assets allow them to operate in a network of assets, generating information exchange and contributing to the analysis and action-making from the information generated by that network. Project managers mentioned the factors that agree with O'Donovan et al. (2015), thus highlighting that data-driven solutions contribute to the development of operations and asset maintenance. However, training and planning are still needed for effective use of technologies and information generated, which emphasizes the lack of a team to analyze information and decision making. The analyzed projects converge conclusively, indicating that data-based decision making represents an increase in productivity and a higher return on assets, as postulated by Mandinach (2012) and Brynjolfsson, Hitt, and Kim (2011). Gaps in understanding the adoption of building technology at the organizational level were identified, particularly about supplier involvement in the process. All technologies studied were considered after the start of the project. Addressing the research question, this study has shown that technology is adopted differently at each phase of the asset's lifecycle. Few companies consider the importance of technology and plan for its effective use in the acquisition and commissioning phases. In the operation and maintenance phases, technology adoption occurs more intensely; in the last phase of the asset's lifecycle, technology is sometimes not considered. This study shows the main factors that influence the adoption in each phase of the asset's lifecycle. Thus, we can conclude that companies fail to effectively leverage the tools available in the market because they do not consider some important factors for adoption and do not visualize the importance of technology in the early and late stages of its lifecycle. According to the results, the capital projects in the future will incorporate digital technologies and operate far differently from today. In this scenario, given the complexity of AM in projects, digital technologies enable connectivity and sensing, automation, process digitization, and advanced analytics. These technologies allow company to progress through their digital capability journey.

Theoretical Contribution

The theoretical contribution of this study is related to the integration of the Smart Asset Management concept with the TOE and TAM technology adoption models. Intelligent AM can provide a framework for validating and improving asset performance by collecting and incorporating reliable asset information into decision making. The integration of AM and technology adoption concepts allows us to develop a theoretical framework for technology adoption into complex projects, leveraging the potential of information technologies in their business activities and strategies.

5. CONCLUSION

Based on the overall objective of the study, there was a need for a substantial change in organizations that involves a departure from existing routines and a shift to new types of competencies that challenge, complement, and enhance organizational knowledge. The implementation of technology is multidimensional, and its successful implementation depends on several factors. In addition to the issues of standardization and integration of new technologies with existing technology infrastructure, many human, social, and cultural issues hinder the optimal use of technology. IT adoption is considered an important result in companies' efforts to leverage the potential of technologies in their business activities and strategies. Thus, the study allowed the identification of variables that affect the adoption of technologies focusing on AM in complex projects, which allows managers to establish best practices for their adoption. An analysis of technology adoption and the assets' lifecycle showed that in the cases under study, the technological tools were only effectively used in the operation and maintenance phases, while minimally used in the acquisition and demobilization phases. Smart AM can provide a framework to validate and improve asset performance by collecting and incorporating information from trusted assets in the decision-making process. Most companies use various assets in their operations; however, companies use inefficient methods, such as inspections once or twice a year, rather than using technology to manage their assets. AM with embedded technology allows managers to improve accuracy and provide real-time position information, thus reducing the manpower, time, and cost for the management work. Future studies should include a longitudinal study in complex projects, apply the integrated concept of AM with technology adoption models, and analyze the inclusion of technological tools in AM. Assimilating technologies requires organization-wide adaptation of the, so integrated testing of the application of concepts can help develop a technology adoption model for engineering and infrastructure AM. Additionally, future research should focus on the alignment between processes and technology and its impact on project performance. Researchers could also focus on developing a quantitative study to validate the adoption factors discussed throughout this study. Finally, future research could reinforce analyses that indicate the technological level of equipment and AM and its relationship with profitability in companies or projects. As regards limitations, first, because it is qualitative research, this study results cannot be generalized, considering that it is based on four infrastructure projects. Another limitation is the representativeness of individual speech concerning a larger collective. In an attempt to minimize the impacts of these limitations, secondary data, project reports, and contacts with equipment suppliers were used as a basis for the interviews.

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