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RESEARCH ARTICLE

Leveraging AI-Enabled Digital Twins for Smart Advertising Design and Testing

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Abstract

Advertising design and creativity play a pivotal role in advertising strategy. In the era of digitalization, there are many emerging technologies, such as Artificial Intelligence (AI), Internet of Things (IoT), Virtual reality (VR), Cloud and Fog Computing (FC), which were developed for use in many design and development of smart systems. These technologies with other autonomous devices, technologies, surveys, models, and software are creating extensive, complex, and diverse advertising data sets. These data diversity and heterogeneity may hinder advertising studies. Thus, there is a clear need to synthesize, synchronize, integrate, and interoperability the large-scale data sets according to predefined decision rules and research objectives. Against this backdrop, this paper introduces a new platform of data integration and modeling— Advertising Digital Twins (ADTs). Digital twins (DTs) are virtual copies of products, services, processes, ads, campaigns, or humans encompassing all the relevant entities' elements. Although numerous research studies have been published on DTs, none hitherto have been conducted in marketing communication. This paper aims to bridge two perspectives: on one side, the authors acknowledge the value of ADT as a data fusion platform. On the other side, the authors build on previous scholarship to suggest a conceptual framework for implementing this platform in future advertising studies.

Keywords: Digital Twins (DTs), AI, Advertising Creativity/Design, Human-In-The-Loop (HITL), MarketingIoT, IMC, Data Fusion.

1. Introduction

"One of the most promising enablers of Smart Systems is the Digital Twin" (Kherbache, et al., 2024, p.25). Advertising design, creativity, and testing are inherently complex and error-prone decisions. Advertising creativity is the use of imagination or original ideas within a strategic context to advance a marketing objective(Alstiel et al., 2019). Modern advertising (ad) configurators need to manage an overwhelming amount of possible combinations because of the high variety of design elements, a large number of consumers' responses, heterogeneous data sets, and environmental factors that can influence adseffectiveness (Eisend and Tarrahi, 2016; Goldberg et al., 1999; Hornik, 2016; Rosengren et al., 2020). Much research has been conducted to investigate the relationships between advertising elements and consumers' responses, to identify the conditions under which specific ad approaches or combinations of elements (e.g. layout, appeal, text (copy), format, colors, symbols, slogans, images, contrast, unity, aesthetics, presenters), will leverage ad effectiveness (Dagalp and Sodergen, 2023; Derda, 2024). Despite the rich empirical and theoretical work, advertising design remains a subjective and intuitive process. Managersstill make design decisions largely based on experience with past campaigns, creative insights, and intuition rather than on sound research and data (Burke et al., 1990; Kitchen 2023; Dagalp and Sodergreb, 2023Smith and Zook, 2024). However, in recent years, the ad design and testing process is moving to evolve into a comprehensive digital era. The recent digital transformation in advertising is

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an effort to secure competitiveness by leveraging digital technology to adapt to the changing ads environment (Campbell et al., 2022; Weigold et al., 2024). Digital transformation has become the source of such changes. In fact, things that used to exist only in analogue form have now been converted to digital form. Various computer- aided technologies, i.e. Computer-aided design (CAD) and computer- aided advertising (CAA), are available to assist advertisers and ad agencies to effectively generate novel creative ads (Duan and Heng, 2018; Guo et al., 2021). CAD software used to be a fundamental tool to create 3D models for design assistance and verification. However, with the new digital technologies CAD has been proven to be a limited tool for ad designers (Helberger et al., 2020). Also, CAA did not reach its full potential for ad design and testing (Derda, 2024; Huang and Liu, 2022). While many advanced technologies have been widely used in different design systems, especially in architecture, products, and the arts, surprisingly, the potential of these technologies has not yet been fully recognized by the advertising industry.The widespread adoption of the Internet and digital technologies can profoundly change the advertising ecosystem. While AI has already automated the media buying process, the advertising creative process still requires extensive human efforts (Smolinski et al., 2023). Also, most previous studies have tested ads from a single or few perspectives. No efforts have integrated analysis from different perspectives to explore the reasons for changes in ad effectiveness (Ahn, 2020; Chen et al., 2016; Gordon et al., 2023; Turnbull and Wheeler, 2015). Thus, one of the major pitfalls in ad design and testing arises from the difficulty of integrating the many advanced testing methods and technologies from independent, autonomous data-generating devices, models, technologies, methods, surveys, and software that are generating the large and time-dependent models and data sets (Duan et al., 2018; Smolinski et al., 2023). Clearly, these complex, diverse, and heterogeneous data may hinder the development of ads research and testing (Campbell et al., 2022; Smolinski et al., 2023). Thus, data integration and synchronization is a crucial need in ad studies (Eisend and Tarrahi, 2016; Yun et al., 2020). It has multiple analytical implications, such as conceptualization, illustration, convergent validation (triangulation), development of analyticdensity, and decision-making. Moreover, data integration allows the integration of human experience into the analysis process (Gotz et al., 2023). One type of analytical and data fusion tool that has been relatively overlooked in the current technological frenzy is the use of AI-enabled Digital Twin (DT). DT was defined by the Digital Twin Consortium as a "virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity" (Attaran et al., 2024, p.232). Thus, DT can eliminate guesswork by enabling domain experts to create digital replicas of real Ads. DT can be essential at various points in the ad design and testing process, to help highlight strong genres, formats, styles, and segments, demonstrate concepts, aesthetics, testing, reveal potential challenges, enhance Integrated Marketing communications (IMC), minimize design errors, with results that match or surpass human capacity (Barricelli and Fogli, 2024; Wang et al., 2024). This technology harnesses the power of the Internet of Things (IoT), big data, data analytics, AI, and machine learning to inform and enhance decision-making and operational efficiency. DT as a virtual copy of an ad can encompass all the relevant ad elements, as well as consumers ' reactions (attitudes, behavior, emotions), provide recommendations, and predictions. It can effortlessly and bi-directionally integrate data, models, and software, between real and virtual ads. DTs have been applied to a wide variety of designs and testing domains, like, arts, architecture, and products, but, surprisingly received far less attention from ad research and management. Thus, like in architecture and art an Advertising Digital Twin (ADT), can enable new ad designs by building the digital model linkup with the ad or a prototype to improve all aspects of new ad design and testing. Developing and applying ADT in the ad design process will not only optimize the processes but also be beneficial for ad pre and post-testing (Gou et al., 2021).

DTs were stipulated three years in a row among Gartner's Top 10 Strategic Technology Trends in 2019-2022 (Wang et al., 2024). According to Research and Markets (Sharma et al., et al., 2022), the global DT market size is expected to reach $63.5 billion by 2027, an increase of 41.7% throughout 2023-2027. Such rapid growth is indicative of the technology's immense value to diverse domains. Despite the many advantages, applications, and potential of DT technology, a clear gap exists in ad studies, where adoption of DT has been slow coming. This transformative digital technology undeniably holds the potential to revolutionize critical areas of ad research, IMC, and comprise vibrant research areas that raise important theoretical and practical questions. Additionally, it can facilitate remote collaboration among scientists and researchers, accelerating the pace of scientific discovery.

2. Study Objectives

Given that the creation and testing of "a new advertising is a complex nonlinear creative process" (Hornik et al.,2017, p. 306), the present paper has been motivated by the clear need to explore and find integrating systems for the large amount of complex, and time-dependent ad data-generating devices and techniques (Li 2022).To this end, the paper introduces a novel concept, the Ad Digital Twin (ADT), which can integrate, synchronize, and guide research and leverage the ADT for decision-making purposes. Employing a multi-perspectival approach, the intention is to deliver valuable insights into ADT, offering perspective on impactedad effectiveness research. Inspired by recent successful DT applications to various smart ecosystems, we also present a novel conceptual framework for using and conducting research on and with ADTs, specifically for ascertaining possible effects on ad and IMC effectiveness. We follow the general conceptual frameworks and propositional inventories that delineate a conceptual entity in marketing research (MacInnis 2011). To advance these objectives, precisely during an era inwhich scholars are calling for more conceptual work (e.g., McAlister et al., 2023), we provide an overview of DT, ADT, and related concepts relevant toad research.Our conceptualization integrates into the ADT's repeatability, integration, precision and predictability, the human intelligence and intuition concept (Human-In-The-Loop, HITL; Retzlaff et al., 2024). Specifically, grounding our research in the extant DT reviews and meta-analyses (e.g. Correia et al., 2023; Kukushkin, 2023), the broader lay discussion, as well as our qualitative analyses the conceptualization benefits from the five dimensions DT (and ADT) framework (Mirza, 2021; Sharma et al., 2022;Tao, 2019),by leveragingthe Computational Creativity Theory (Caetano et al., 2020; Colton et al., 2012; Mejia et al., 2021), and the HITL concept.In sum, the novelty of the paper is the introduction of ADT as a unique ad data fusion system. Furthermore, positioned as an important contribution within the emerging DT-focused literature, we apply this novel hybrid theoretical framework not only to address the theoretical and practical advantages of the prescribed approach to ad design but also to highlight some important avenues for future research to advance and improve computational ad design and testing as a decision-enabling platform. Each of these endeavors requires additional details, which due to readability considerations and space constraints, we furnish in an extensive online (Web) supplement. Thepaper, we hope, will serve as a valuable reference for ad scholars and practitioners and foster future conceptual and practical research innovations in ADT-driven ad effectiveness.

3. Digital Twins: A Brief Review

IKEA utilize digital twins of their furniture to create interactive online shopping experiences. Customers can virtually place furniture in their own homes using augmented reality, allowing them to visualize scale, style, and fit before buying. This enhances engagement and reduces buyer's remorse. (Attaran et al;, 2024, p. 101).

DTs are at the core of disruptive innovations in diverse areas (Wang, 2024). DTs are one of the building blocks for the Metaverse which aims to create virtual worlds that merge with reality. In these virtual worlds, images of the real world are created, which can be supplemented by additional virtual artifacts. AI-enabled DTs embody a set of codes, techniques, models, algorithms, software, and data that enable a computer system to develop and emulate human-like behavior and hence make decisions similar to humans (Barricelli and Fogli, 2024). To that end, it also provides different functionalities to handle the collected data and help add value to transform it into knowledge. DTs enable the creation of interactive 3D models, within a virtual space, opening up a world of new possibilities for designers, managers, professionals, and researchers (Attaran et al., 2024). DT technology is considered to be the core digital technology of realizing Cyber-Physical Systems (CPS). Thus, the ADT refers to the full-element reconstruction and digitized mapping of the real ad performance in an integrated multiphysics, multiscale, hyperrealistic, dynamic probability simulation model that can be used for simulating, monitoring, integrating, diagnosing, predicting, and controlling the formation process, state, and behavior of the real ad. Table 1 provides a summary of the various DT characteristics which also apply to TVDT, with more elaborations in Web Appendix 1.

In this paper we argue, that ADT can play a critical role in deploying Marketing IoT (MIoT, Hornik et al., 2023) applications. Advertisers and ad agencies experts can use ADTs to build online digital copies of each ad in a simple form. This digital copy will be designed to simulate campaign strength and limitations, in order to identify possible risks before the original ad fails.In fact, ADTs not only bring automation to advertising, but also will increase the value and innovation in ads and INCs.This hybrid approach could be a paradigm shift in scientific ad research and many ad applications.

Table 1. *Major DT Characteristics.*

Characteristics	Description
State	The value of all parameters of both the physical and virtual twin in their environment
Physical process	The process in the real-system environment that will change or impact the state of the physical twin
Virtual process	The process in the virtual environment (e.g. analytics) that will change or impact the state of the virtual twin.
Virtual environment	The technology-based environment in which the virtual twin exists
Physical entity (Twin)	The real entity (e.g., products, consumers, firms, devices)
Virtuality	The virtual digital twin synchronized with the physical entity.
Synchronization& Integration (Twinning)	Real-time integration and convergence of physical systems and its digitalcounterpart
Twinning rate	The rate or frequency at which synchronization occurs
Networking devices	Physical or cloud-based communication devices for data exchange
Cloud computing	The delivery of computing services, including servers, storage, databases, networking, software, analytics, and intelligence—over the internet ("the cloud") to offer faster innovation, flexible resources, and economies of scale
Data storage	Acquiring historic data of an entity for data comprehension
Heterogeneous data Self-adjustment	Ability to handle large amount of data from different sources and formats. Self-adaptation and parameterization capabilities following changes in the system during its lifecycle
Information selection	Identifying, extracting, and storing useful information
Pattern identification	Identifying changes and trends by data analysis
Physical-to-virtual connection	Presents the data transfer pf physical entity to the virtualenvironment
Close-loop feedback	Feedback provided to the systems and other digital twins,using interfaces to assess the computing information
Metrology	Measuring the current state of the physical/virtual entity
Optimization	Achieving best outcomes while addressing datauncertainty
Simulation	Representing current status and what-if scenarios
Location	Enables users not co-located to collaborate in design and implementation/

4. Related Literature

In this section we briefly discuss the major ad design and testing analytics which are producing the very large and heterogeneous data sets to be used by AD Tintegration algorithms for enhancing campaign outcomes.

5. Advertising Design

"Art and advertising have a long and intertwined history and are not as distinct from each other as they may initially seem" (Derda 2024,p. 67).

Advertising creative design is crucial for any advertising campaign since it has a significant impact on ad effectiveness, sales, and relationships with advertising agencies (Rosengren et al., 2020). There is hardly any industry that fetishizes creativity as much as advertising. From having "creative directors", "chief creative officers", "creative strategists", or even "creative technologists" as central stakeholders and decision-makers in advertising agencies to industry events with "festival of creativity", "Clio Ad Awards", or "creative circle" in their headings. The ad industry makes creativity central in everything they do, while ad researchers try to evaluate the role that the manyad elements play, as ads are "highly complex combinations of print and color" (Hornik et a, 2017, p.306). The understanding of these elements (signs) comes from the discipline of semiotics, defined as the "theory of signs" (Colton est al., 2012). The theory facilitates a better understanding of how messages should be designed for persuasion.Thus, semiotics and semantics must be at all times considered due to the fact they directly inform design decisions by explaining the complex relationship between recipient, message and interpretation (Chen et al., 2019).

Key elements of advertising design include: Visual Elements like,images, graphics, colors, intended to create an appealing and eye-catching design. To advance visualizationdesigners' can use the concept of Visual Hierarchy (Eldesouky, 2013), to establish a clear visual hierarchy toguide the viewer's attention through the ad. In addition to visual elements, other design facets are classified within typography, layout and balance, message,contrast,branding, target audience consideration, platform specificity, and white space (Elaborated in Web Appendix 2, and Altstiel et al., 2019). Creativity is linked with art and therefore the common approach to ad creativity is also linked to uniqueness, artistry, imagination, or even unexpectedness (Derda, 2024). Thus, this approachto creativity goes beyond the notions of technical proficiency and instead values a more holistic approach to advertising that incorporates artistic notions. The convergence of advertising with other creative industries can assist ad design and creativity while advancing “computational creativity”. This can guide advertisers to use digital technologies how to design more creative ads, to communicate a message to a large group of consumers faster and uniquely than any traditional analog form ofcommunication.

6. Computational Creativity

Computational creativity focuses on the development of computational models and systems capable of exhibiting creative behaviors. It seeks to understand and replicate the processes involved in human creativity using computational methods (Othman 2017). Recent advances in generative AI, especially in natural language processing (NLP) and computer vision have dramatically expanded what these systems can autonomously produce. Indeed, models like DALL-E 2, GPT-3, AI chatbots as Google’s LaMDA and Anthropic’s Claude can propose natural-language messages (Derda, 2024; Duan., 2018; Golab., 2023). These models enabled new creative applications. For example, DALL-E 2 has been used by artists to compose novel images as inspiration for artworks. GPT-3 is used to generate copy, slogans, logos, and other advertising and branding content from basic prompts. Caetano et al, (2020)proposed AI’s as apotential technology for automating graphic design tasks like generating logos, posters, and print layouts. A leading concept in advancing computational design is “The Generative design” approach (Cui and Tang, 2017), which involves using computer algorithms to explore and generate a multitude of design possibilities. The primary goal of generative design is to explore a design space, discover novel solutions, and optimize designs based on defined criteria. Generative design tools are becoming increasingly popular, enabling designers to leverage the power of computational algorithms for creative and optimized design solutions (Hartmann et al., 2023).

7. Computational Advertising Design

Computational design in advertisingrefers to the use of computer algorithms, programming, and automation to create, optimize, and execute design elements within advertising campaignsHelberger et al., 2020). Like the general computational design, it involves leveraging computational tools and techniques to enhance the creative and strategic aspects of advertising, making the design process more efficient and data-driven. Computerized systems for advertising design typically involve a combination of hardware and software tools that facilitate the creation, editing, and management of advertising signs and content. In practice, the integration of all design models and software covers all necessary ad elements to design the optimal ad according to the prescribed advertiser’s ruleor objective (Derda, 2024). Thus, a computational model for an ad design follows the aim to optimize the combination of the different design elements to achieve a more creative ad.It might include various considerations such as ad alignment, shapes, proportions, colors, rhythm, contrasts, sizes, positioning, and harmonious feelings, elements that might have an important role in the design process, directly influencing readability, interpretation, and engagement (Bo et al., 2018).

Another notable model which is based on algorithmic computation is the Creative Advertising System (CAS) proposed by Vakratsas and Wang (2020) for the generation and evaluation of creative advertising ideas. The model approach is similar to the Goldenberg et al. (1999), creativity templates which contends that a substantial part of creative behavior is guided by abstract fundamental schemes. Some other models were part of a wider research attempts to formally develop a “Computational Creativity Theory” (Colton et al’, 2012; Lennon, 2017; Mejia et al., 2021). This theory that is based on the FACE and IDEA models (Colton et al., 2012). The FACE model includes the following facets: Flexibility: The ability of a creative system that can generate a diverse range of ideas or solutions. Adaptation: The ability of the system to be able to adapt its approaches or strategies based on feedback or the changing of external conditions. Combination: Combining different elements, concepts or ideas in novel ways to produce original outputs. Exploration: The system should engage in exploration of different modules to discover new design solutions. Thus, the FACE model outlines key attributes that might contribute to creativity, emphasizing the importance of generating diverse ideas, adapting to circumstances, combining elements in novel ways, and exploring various options. The IDEA model provides a structured approach to understanding the creative process within computational systems, highlighting the stages of Idea generation: The system should be capable of generating novel ideas. Diversity: The generated ideas should be diverse, covering a wide range of possibilities. Evaluation: There should be mechanisms for evaluating the generated ideas to determine their quality or appropriateness. Adaptation: Similar to the FACE model, the system should be able to adapt its strategies based on feedback and changing requirements. Collectively, the two models can distinguish between whether an artefact is valuable or not, and whether a system is acting creatively or not, with focus on the latter (Mejia et al', 2021). Both models serve as theoretical frameworks for designing and evaluating creative systems, guiding researchers in understanding how computational processes can mimic human creativity. Similarly,Programmatic Creative Platform (PCP) also consists of two models, the Dynamic Creative Optimization (DCO) and Programmatic Advertisement Creation (PAC) (Chen et al., 2019). DCO can test in parallel the performance of many variations of addesign in different contexts at the same time. By analyzing the real-time performance data by using machine learning algorithms, DCO can help PAC improve ad content immediately. The ultimate goal of PCP is to generate large-scale personalized, contextualized, and creative ads in real-time. "Ahn (2020)." introduced the ADTECH model that includes tools, software, platforms, and technologies to be used in the digital advertising ecosystem. Adtech encompasses a wide range of technologies and processes designed to optimize the delivery, targeting, tracking, and analysis of advertising campaigns. This includes, for example, Ad Serving Platforms which is a software platform that delivers ads to websites or mobile apps based on predefined criteria such as targeting parameters, user behavior, and bidding algorithms.

In sum, the umbrella term "computational advertising design" encompasses a wide array of hybrid computational systems, models, software, and technologies. All referring to an ad ecosystem with effective computing capabilities, that can employ mathematical, physical, IT, economic, and strategic approaches to fully represent a rich set ofad designs, which can be fully integrated by ADTs.By combining all the models and software using ADTs, ad professionals can create visually appealing and persuasive design ads that effectively communicate their messages and enhances the desired consumers' responses.

8. Advertising Testing

Advertising testingor copy testing, involves various methods to evaluate the effectiveness of an advertisement before or during use. These methods help advertisers understand how their target audience perceives the ad, its message, and its overall impact in the forms, for example, ad impression, click-through-rate (CTR), conversion rate, cost per lead (CPL), engagement rates,brand awareness.The main methods of advertising testing are pre-testing using, for example (Eisend, 2016; Gordon et al., 2023), concept testing(surveys, focus groups, or in-depth interviews). Storyboard Testing (focus groups or online surveys). Copy Testing (surveys, eye-tracking studies, or facial coding). Live testing like A/B Testing (split random consumers). For post-testing, using tracking studies (surveys, sales data analysis, social media monitoring. Sales Lift Analysis(comparing sales data before, during, and after the ad campaign).Experimental Methods of lab or field tests (Eye-tracking, EEG, heart rate monitoring, and facial coding. controlled trials in select markets or locations).Digital and Online Methods (Structured online questionnaires). Social Media Analytics (monitoring likes, shares, comments, and sentiment analysis). Click-Through Rate (CTR) Analysis. Qualitative methods (Focus Groups), in-Depth Interviews. The more recent tests like Automated and AI-Driven Methods for Predictive Analytics (Machine learning models and algorithms). Sentiment analysis (Natural Language Processing (NLP) tools). These methods provide advertisers with a comprehensive understanding of how their ads are perceived and their potential effectiveness, allowing for optimization before wide-scale deployment. Most important, by using a combination of pre-testing and post-testing methods, and the integration of the many and varied methods,advertisers can gain valuable data and information into how their ads are performing and make adjustments to improve their campaigns (Hornik et al., 2026).

9. ADTs Data

Data is the cornerstone of any DTs system (Attaran et al., 2024). AI-enable DTs generate vast amounts of data, which can be analyzed to derive valuable insights and more informed, evidence-based decisions across various domains. Since massive multisource heterogeneous data are generated during the operation of a physical ad, big data analytics technologies are required to collect, transmit, store, and process the data. For a full ad design process designers need first, ad-related data. Second, media data. Third, relevant consumer data. Fourth, is environmental data (Chen et al., 2019; Derda 2024).

Advertising Data: The basic purpose is to extract and derive data that are valuable and meaningful to a particular ad decision process from large, potentially cluttered, big data. These might include, for example, ad databases or "advertising libraries" (Chen et al., 2019) such as Kantar's platforms, iSpot.tv, or publicly available sources such as "ads of the world" and the YouTube-8M project (Duan and Yang, 2018), which cover current and past ad ideas. The mass data for the ad design process can be continuously analyzed in real time by emerging computing technologies, i.e. cloud computing, fog computing, and machine learning. Then, the results can make change automatically, and assist the ad designers in making informed decisions. Also, the MIoT data offers several options for advertisers to assist smart ads using a variety of differentprogramming architectures (e.g., SmartThings, OpenHAB, and Apple Home Kit; Guo et al., 2021). The MIoT ad middleware will be able to adapt and convert the current fragmentation of the IoT world into a common language to enable smart advertising (Vakratsas and Wang., 2020). Similarly, multiplecombinations of standards and protocols areavailable for generating ad data, for example, for communications: IPv4/IPv6, RPL,6Low-PAN; data: MOTT, CoAP, AMPQ, Websocket; for management: OMA-DM, TR-069; for data transport: Wifi, Bluetooth, LP-WAN,NFC; for discovery: Physical Web, mDNS, DNS-SD; for identification: EPC, uCode, URIs; Yun et al., 2020). Also, the advertising academic literature is rich with many quantitative meta analyses (Eisend and Tarrahi, 2016; Eisend, 2017; Hornik et al., 2017) which provide valuable statistical data for decision making (Rosengren et al., 2020).

Building a unified data sharing warehouse as the source of information in a DTs system is a major task in any DT architecture. The whole ADT system will consist of data generation, storage, transmission and processing. Big data analytics may be used for algorithmically searching for information that is hidden in a large amount of data. Commonly employed data mining algorithms in DTs usually include K-means algorithms (Holmes et al., 2021), the expectation–maximization algorithm, the nearest neighbor approach, the naive Bayesian model, and classification and regression trees (CART), etc. Predictive analytics can be used to leverage historical data to uncover real-time insights and predict future events. To address multisource heterogeneous data, data fusion will be employed for the collection, transmission, synthesis, filtering, correlation, and synthesis of useful ad campaign information from various information sources (Kalantari et al., 2022).

Media data: The virtual reality (VR), augmented reality (AR), and hologram technologies can be applied to the media which will provide all necessary media data (Grubel et al., 2021; Smith and Zook, 2024).

Consumer data: The ever-expanding network of Iot and MIoT devices is making it increasingly easy to access information on not just consumers' consumption behaviors but also every activity they undertake on a daily basis (Sun et al., 2021). Devices ranging from wearable gadgets, virtual assistant devices, data silos (data repositories), social networks, and software applicationsto smart technologies are making a plethora of rich, real-time consumers' data. The gathered information can include web browsing history, e-commerce history, purchases, communication content (e-mail topics or content shared on social networking sites), media consumption (videos watched or playlists), or click-through responses to ads (Chen et al., 2016). Kosinsky et al., 2015 showed that easily accessible digital records of behavior, Facebook Likes can be used to automatically and accurately predict a range of highly sensitive personal attributes including: sexual orientation, ethnicity, religious and political views, personality traits, intelligence, happiness, use of addictive substances, parental separation, age, and gender. In addition, Biometric customized advertising technology can provide personalized automatic ads through biometric recognition such as iris, face, and fingerprint. Thus, the consumers' data will consist in tracing purchase history and recently viewed products to individualize advertisements accordingly. Because of its ability to rapidly process data on customers and their browsing histories, the ADT technology will be able identify persuasive contents and ad illustrations tailored to customer preferences.

Ad research shows, that effective ad designs should also appeal to customers' emotions. These data can be extracted from many of the customers´ sensory levels. Indeed, advanced techniques for emotional analytics leverage cutting-edge algorithms and technologies to understand and interpret consumer emotions more effectively, fostering effective communication, enabling target advertising, and improving ads decisions (Haase et al., 2020; Yang and Smith, 2009). Using for example, Natural Language Processing (NLP), used to analyze text data, such as social media posts, customer reviews, and support tickets, to extract emotions and sentiments expressed by consumers (Kliestik and Lazarois, 2023). Advanced NLP models, like transformer-based architectures (e.g., BERT, GPT), enable more accurate sentiment analysis and emotion detection. Also, Emotion Detection in Multimedia, for analyzing emotions in multimedia content, including images, videos, using computer vision algorithms that can detect facial expressions, body language, and other visual cues to infer emotions. Other technologies being developed include EmotionML, a proposed standard for an emotion markup language to allow software to respond to the detected emotional state of the user from the Computer Expression Recognition Toolkit (CERT) for classifying emotions from facial expressions, eye tracking, analysis of speech, gesture, movement, as well as internet, social media, and smartphones (For a recent review see Gonzalez and Martin, 2024). A typical smartphone contains multiple sensors such as internal motion (accelerometer), gesture, ambient light, magnetometer, gyroscopic, temperature and humidity, and barometer. The communication interfaces commonly found on a smartphone are Wi-Fi, GPS, near field communications (NFC), Bluetooth, and infrared (IR) LED. Many additional sensors are available for physiological measurements. Research into the use of physiologic sensors to measure emotion is underway, including skin conductivity, heart rate, respiration, blood pressure and EEG, and EMG.Using ChatGPT conversational chatbot, emotions will be recognized from text-to-emotion analytics (Kliestik and Lăzăroiu,2023).

Environment factors, e.g. competitive environment,market demand, economic situation, and supply chain structures, all are important components of ADT, which provides information necessary to secure the consistency of physical ads and virtual ads. Collect and integrate information on all elements, and precisely predict the change in the environment. Thus, environment coupling technology is required to consider the effect of environmental factors on the ad design and testing process (Hassan et al., 2022).

Simulation: The real ad data synced with the digital model can simulate the situation in virtual space. ADT can simulate the ad result in real-time and bases on “what-if” methods (Kalantari et al., 2022). Some simulation software (e.g. Matlab, FlexSim, and Simul8; Mirza, 2021), can support ADT-based simulation that enables real-time data analysis (e.g. machine learning and deep learning) and communicates with the Internet-connect devices. The simulation can be continuously operated in the process for decision-making and optimization. Unlike regular simulation models, DTs connect to their physical counterparts supporting bidirectional relationships, receiving real-time data to monitor their performances, controlling their processes and functions, and providing insights, such as diagnostics, prognostics, and recommendations. Additionally, DTs are able to create metadata (information about information) from the various smart monitoring devices (Gonzalez and Martin, 2024).

10. ADTs Models and Supporting Technologies

The second pillar of any DT is the related models, software, and supporting technologies (Sharma et al., 2022). Like regular DTs the major advantage of ADT is the ability to integrate all the design models according to the defined rules and the recommender system. Several types of models play crucial roles in enabling ADTs, each with specific strengths and purposes. The key categories are (Sharma et al., 2022; Stacchio et al., 2022). Data models: These define the structure and relationships of the data associated with the real ad. They determine what information is captured and represented in theADT, ensuring consistency and coherence. Ontology models: Capture the relationships and concepts surrounding the ads using structured vocabularies. Machine learning models: These models use historical data and statistical techniques to identify patterns and make predictions about the entity’s behavior. Predictive maintenance models: Forecast potential failures and optimize maintenance schedules. 3D and CAD models: These provide a visual representation of the asset’s geometry and components, often serving as the foundation for other models. They can be static or incorporate dynamicfeatures based on sensor data. Hybrid models: Combine elements from different categories, leveraging the strengths of each for comprehensiveADT. As outlined before, in addition to the commonly used CAD other hybrid models were developed for computerized design tasks. For example, by leveraging the generative design framework that supports the automatic generation of a large number of design solutions with computer algorithms that can be selected and controlled by a designer (Park et al., 2024; Shi et al., 2023). With such a framework, different ad design can be developed by using the same system prototype but with different initial design representations and selections of transformation methods. In the ADT framework virtual ads can be designed to include physical ads with high precision by integrating multiple different types of models and software, that cover all the necessary ad design elements, such as graphic design software, including, Adobe Creative Cloud (Photoshop, Illustrator, InDesign); Industry-standard software for graphic design, image editing, and layout design. Desktop Publishing Software such as CorelDRAW. The latest DiffusionDB is the first large-scale text-to-image prompt dataset totaling 6.5TB, containing 14 million images generated by Stable Diffusion models (Al habeebnand Al-Shargabi, 2024). Also, the previously discussed design models like DALL-E2, Googl's LaMDA GPT-3, CAS, etc (Derda 2024). The fact that ADTs can simulate interaction with a given market place environment supports the notion of its immersive power, especially if the ADT serves as a substitute for physical ads. The integration of the models according to predefined rules will assist in prediction, scheduling, configuration, optimization, and other objectives, so as to ensure the effectiveness and reliability of the change control when it is sent to the physical network.

11. CDT Fusion Capabilities

The preceding review was primarily intended to provide an impression how very large and diverse are the ad design and testing methods. A common problem encountered in such evidence-based methods is that they cannot collect all essential information from one source or sample, and they may need to link non-overlapping data items across independent studies and samples. The ADT data fusion as a solution to this problem.Data fusion techniques particularly play a significant role in the DT framework. The flow of information from raw data to high-level decision-making is propelled by sensor-to-sensor, sensor-to-model, and model-to-model, sensor-to-technology fusion. As already noted, one problem with ad research is that it is experiencing a continual increase in fragmented data and knowledge with little or no integration and thereby risk of being overwhelmed, confused, and misled by the ever-growing piecemeal evidence.

The proposed method is not restricted to specific types of variables and distributions. DT require no prior knowledge about how data at hand may behave differently from standard theoretical distributions, and it automate the process of generating suitable distributions that match data, therefore making this method particularly useful for linking data with complex distributional shapes (Grubel et al., 2021/). In addition, DTs have strong theoretical support,and permit highly efficient direct fusion to relate a mixture of continuous, semi-continuous, and discrete variables (Gotz et al., 2020).What makes the DT concept unique is the convergence of five cutting-edge technologies, integration of within and between varied data/information sets, and models, and DT interoperability (Ferko et al 2023; Gotz et al., 2020).

12. Technologies Convergence

The DT is the convergence of five advanced technologies, namely Big Data, AI, Multi-Modal Interactions (MMI), Cybersecurity, and Quality of Experience (QoE)-powered Communications (Lyu 2024). Big Data technology with the massive amount of data collected using predominantly the IoT and Social Networks (SN) as its main sources. Data collection using the MIoT with the widespread use of sensors, cloud and fog computing, and SN with their rapid and increasing adoption, will be the basis of the ADT. Indeed, it will facilitate increasingly vast measurements of data about the real ad. This data will be secured using the latest advances in Cybersecurity (O'Connell et al., 2023). Then, this data will be subjected to advanced AI algorithms to extract information on the real ad from multiple aspects. MMI will bring the digital and real ads together in a seamless reciprocal influence, which on the one hand will improve the quality of data of the real show, and on the other hand, will allow the ADT to evolve based on measured and recorded interactions of the real show. This interaction will happen over highly performing networks to ensureQoE-powered Communications (Li et al., 2022).

13. Data Integration

"Digital Twins Thrive on Data Integration "(Tao and Qi, 2019, p.490).

Advanced ADT technology will be equipped with data fusion software (Correia et al., 2023; Ferko et al., 2023) which can integrate multi-type data including homogeneous, heterogeneous, structured, non-structured, temporal, and non-temporal data.Ad monitoring lacks a sense of how the many splinters of knowledge fit into a unified conceptualization of information processing. It also lacks an understanding of the relative importance of the many behavioral, cognitive, and emotional responses for explaining ad success. Therefore, ADTs have the potential to revolutionize the way ads and audiences are monitored and managed, by providing managers with real-time integrated and synchronized ad data. Advances in integrated cloud-edge computing mechanisms with ubiquitous connectivity and AI are important for the development of ADT. An integrated cloud-edge computing framework will facilitate the development of ADT by ensuring that low-latency and storage solutions are provided while integrating real-time data and massive historical experience (Barricelli and Fogli, 2024). The collected data will be integrated into a centralized repository or platform, similar to the process of any DT. This integration may involve data normalization, cleaning, and transformation to ensure consistency and accuracy across different sources (Gotz et al., 2020). Data can be integrated by storing information from different sources on a specific platform, such as a cloud or fog as well as a non-premise platform. An example of a cloud-based platform is MindSphere™, which has been used in the EITFood project (Liu et al., 2019). The emergence of CDT technologies will offer a promising a venue for improving decision-making through the integrated use of up-to-date physical or synthetically simulated data. By leveraging software and hardware integration tools like MATLAB, Simulink, AWS IoT, IBM IoT, and Microsoft Azure IoT Hub CDTs. Also, fusion approaches based on machine learning are usually used for pre-processing or classification. Typical techniques include Support Vector Machine (SVM), KMeans, etc. They are widely used in healthcare, transportation systems, manufacturing, human-machine interaction domains, and so on (Wu et al., 2021). Approaches based on deep learning like convolutional neural networks (CNNs), recurrent neural networks (RNNs), deep Boltzmann machines (DBM) and their variants, etc. DL-based techniques perform well on discriminative feature learning. These techniques are beneficial for the fusion of text, image, audio, video, or physiological signal data (For a review see (de Koning et al., 2023). All will allow the integration and consideration of holistic perspectives of the investigated ad. It breaks down data silos, eliminates redundancies, and makes information more accessible for analysis and decision-making. They ensure data consistency, accuracy, and accessibility across the investigated domain (O'Connell et al., 2023). Consequently, just as DT is able, with considerable success, to treat and synthesize digital data with decision support software for smart cities or smart healthcare, monitored by some of the same devices employed for ad monitoring, it should be capable of bringing together and 'hybridizing' various smart devices and associated big data for smart ads and IMCs(Li, 2022). By creating a virtual replica of the ad, managers will be able, by way of data and model integration, to simulate and test various scenarios before implementing them in real marketplace. Ensuring a unified view of the real entity and enabling powerful applications like predictive maintenance, recommendation systems, performance optimization, and remote monitoring (Ma et al., 2024).

The wide adoption of the DT concept necessitates prioritizing the interoperability that is required to allow seamless access to data and to facilitate data exchange which will in turn enable making sense of the data (O'Connell et al., 2023). In addition, the DT is an Internet-based platform and makes interoperability necessary to allow for multiple end-to-end systems to interact, which provides elastic, universal connectivity and standards-based capabilities.Finally, to achieve an acceptable QoE from, for example, video, voice, olfaction, gustatory and haptic data streams will need to be synchronized. The research in the literature has discussed different synchronization techniques along with their uses and requirements (Correia et al., 2023). Buffering schemes and Fog Computing, are examples (de Koning et al., 2023).

14. Fog Computing-Enabled ADT

Fog computing is a computing paradigm that extends cloud computing and brings computing and storage capabilities closer to the devices where data is generated. This makes it ideal for applications that require real-time or near-real-time processing of large amounts of data, such as DTs. "Digital twin technology empowers fog devices to be intelligent in their actions and reactions" (Pushpa and Kalyani, 2020, p.71), recently applied in marketing research (Hornik et al., 2023). Moving ADT to the edge of the network will facilitate smarter applications for the following reasons: first, reduction in latency; second, ADT analytics can guide local control and vice versa; third, using machine learning platforms for streaming data, ADT will operate much faster and acquire the ability to self-learn; fourth, fog computing technology implements decentralization of data, and distribution in the network, thus preventing hackers from corrupting data; fifth, transfer of sensitive information over networks will be minimized and thus data security will be maintained; sixth, the volume of data that must be transmitted to the cloud can be reduced, thus reducing cloud storing costs; seventh, sensitive data need not be sent to the cloud; eighth, analytics can be performed even when the ADT system is disconnected. In sum, by merging these two emerging technologies, stakeholders will be able to develop devices that can perform intelligence capabilities and that possess immense decision-making capabilities without human intervention.ADT Interoperability Another unique capability of DTs is the interoperability ability between systems within close domain systems. Thus, interoperability might facilitate collaboration and coordination between different ad campaign stakeholders who create ADTs for various aspects of a campaign,using multiple channels and touch points like IMC. Interoperability will allow these ADTs to collaborate, share data, and coordinate their actions effectively (Li, 2022). Also, interoperability will ensure that data can flow between different ADTs and other ads in a standardized and compatible manner. This will enable a comprehensive analysis, better decision-making, and enhanced operational efficiency. Advertiser can deploy ADTs across different domains or phases of a campaign. Interoperability ensures that these ADTs can scale as needed and adapt to changes in the campaign without requiring extensive modifications. In a complex situation such as ad campaign,interoperability will enable seamless integration of ADTs with other marketing systems like MIoTs, ad media, channels, sensors, and devices. This integration will support holistic management, optimization of resources, and the realization of broader marketing objectives like IMC. Overall, ADT interoperability will play a pivotal role in leveraging the full potential of multiple ADTs across diverse ad campaigns and applications promoting efficiency, collaboration, and innovation within interconnected ad ecosystems (Gotz et al., s2020; O'Connell et al., 2023).

15. ADT Conceptual Framework

Our novel conceptualization of ADT is depicted in Figure 1. We adopt the commonly used and empirically validated five dimensions DT (5D-DT;Attaran et al., 2024; Hassan et al., 2022; Kalantari et al,; 2022; Tao et al., 2019), the Computational Design Framework (Colton et al., 2012; Lennon, 2017), including the support of humans' inputs (HITL; Retzlaff et al., 2024) to delineate the ad design process. These integrate the most advanced data and models from smart technologies and devices to support ADT for smart ad design. Thus, we propose a conceptual framework for ADT that captures the combined usage of heterogeneous models and respective evolving data for the entire ad design process.

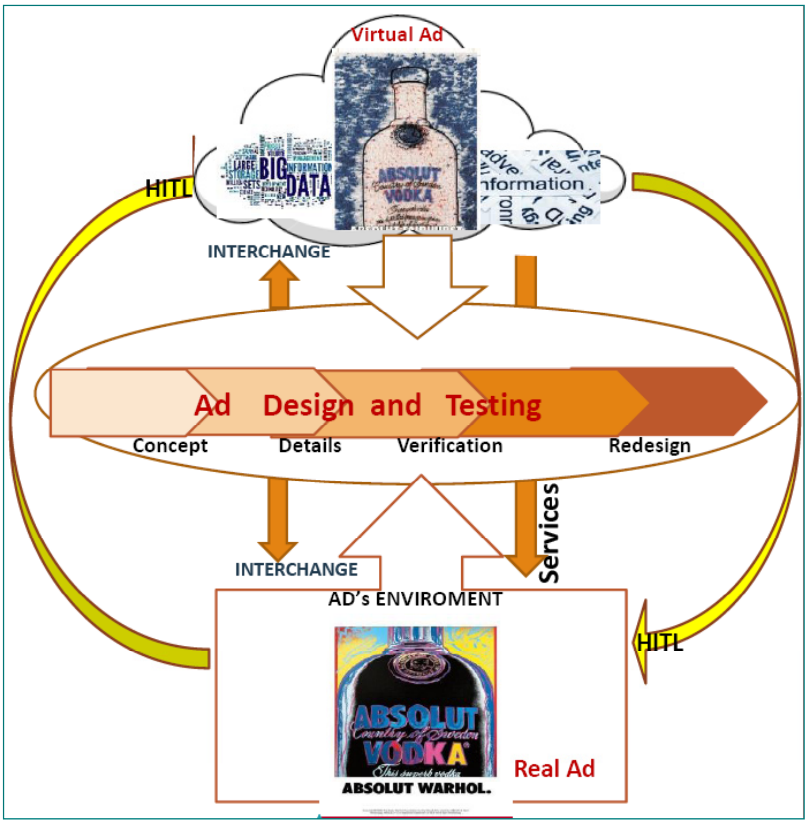

Figure 1. *Conceptual Framework for ADT*

16. The Five ADT Dimensions (5D-ADT)

As previously noted, an ADT is a virtual representation of a physical ad, and its associated environment and processes that is updated through the exchange of information between thereal and virtual ad. As a dynamic model, it consists of five key dimensions (5D-DT; Attaran et al., 2024) that unlock its full potential and are the basis for conceptualization (Figure 1). First, Physical Entity: The real-world object or system that anyDT is based on. It can be anything from a simple machine to a complex infrastructure like a power grid. Sensors or other monitoring systems installed on the physical entity gather data about its operation, performance, cognition, and environment. Second, a Digital Model: The virtual counterpart of the physical entity designed forusing the data collected from the various monitors like, 3D models, mathematical equations, and software simulations. The digital model captures the essential characteristics and behavior of the physical entity in a virtual environment. Third, Data Connection: The vital link that ensures two-way communication between the physical entity and the digital model. Real-time data from monitors flows into the digital model, keeping it updated on the physical entity's current state. The digital model can also send commands back to the physical entity, influencing its operation in real time. Fourth, Services and Analytics: This dimension utilizes the data and insights from the digital model to provide valuable services. These can include integration, performance monitoring, anomaly detection, predictive maintenance, recommendations, and even optimization of the physical entity's operation. Fifth, Real-time Feedback and Optimization: This final dimension closes the loop, allowing the digital model to directly influence the physical entity.

17. The Ad Design Model

"Advertisement design leads to specific associations with the product and is thus of significant importance for product perception and actual purchase behavior"(Derda, 2024, p.54)

The ad design model enablesADT to refer to the synergy of existing physical ads and virtual ads in the design driven by the digital data generated by the ads, and continuously search for new, unique, creative,and valuable ad concepts and transform them into detailed ads. The design plancontinuously reduces the inconsistency between the actual performance of the ad and the expected performance of the design. Several scholars (Altstiel et al., 2019; Colton et al., 2012; Mejia et al., 2021) presented the general design framework using the following design facets: Conceptual design, detailed design, design verification, and redesign. (I) Conceptual design is the first and also the most crucial step of the ad design process. To generate a good creative ad, the designer should consider a large number of data, information, and knowledge from the advertisers, ad market, consumers, and internal agency members. The physical factors (i.e. campaign strategy, function definition, aesthetic design, and ad general market) and the virtual factors (i.e. Model building, historical data, customer reviews, and customer feedback) can providea variety of ADT data for concept generation and assist in improving the communication between advertisers and designers. (2) Detailed design: There are many details and factors to consider, e.g. the ad function, performance, properties, creation process, etc, and the many stakeholders thatare involved in providing the relevant

details. (3) Design Verification: Design verification focuses of ADT for testing and virtual prototyping. It ensures that the design outputs (the actual ad) match the design inputs (the initial specifications and requirements). It involves, examining and analyzing advertisers' specifications and all relevant documents. Physical and simulated tests are conducted to assess if the ad meets the defined requirements. The test results and inspection findings are compared to the initial design specifications to verify if they match.All activities, results, and conclusions are documented to maintain a clear record for future reference. (4) Redesign: ADT at this stage is not only a good prototype for generating a newcreative ad but also provides valuable information for ad improvement and redesign. Digital model can be used to simulate real-world experiences while the computational model provides the numerical values regarding the status of the system based on the real-time collected data. The data provided by these models can support the design decision making in the next-developed ad. However, designing an ad also involves a combination of human creativity, graphic design skills, and sometimes specialized tools to bring ideas to life.

18. Human-in-the-Loop

The human-in-the-loop (HITL) approach might be the unique ingredient that can ensure the success of the ADT-enabled design process. It involves incorporating human expertise, knowledge, and feedback into ADTs. As depicted in Figure 1 HITL refers to a collaborative approach where humans work in conjunction with automated systems to achieve better results. While advanced technology like ADTs can revolutionize ad monitoring, HITL might be a crucial element for comprehensive and effective oversight of ADTs. This approach is often used in situations where AI systems are unable to make decisions or perform tasks autonomously due to complexity, uncertainty, or ethical considerations, typical for ads (Hornik et al., 2017). The sources for HITL might be all stakeholder including design experts, informed managers, agency and ads employees, domain experts, and even customers. Current visual analytics of ADTs greatly upgrade interaction capabilities, steering expert judgement through visually presented aspects of data characteristics (Barricelli and Fogli, 2024; Helberger et al., 2020). HITL systems offer several benefits, including, first, improved accuracy and performance, increased transparency,enhanced ethical considerations,information about changes in regulatory requirements, involvement in monitoring and controlling the ADT, taking part in data analysis, decisions, and recommendations, providing labels and annotations to unsupervised learning data,improving the accuracy of the ADT models, etc. For example, experts can suggest not to use a certain celebrity figure in the ad because of his/her very recent involvement in a public scandal. Finally, consumers can alsoimprove the ADT by providing information that is difficult to obtain by smart technologies, like mood, special individual handicaps, etc(Hassan, et al., 2022). In conclusion, the collaborative abilities of ATDs to the various data-generating technologies, advanced models, and the HITL can lead to newly designed ads, improvements in existing ads, and ultimately to a more appealing campaign. As a novel approach to advertising, the ADT approach and framework offer some significant theoretical and practical implications, while introducing many new avenues for advertising research.

19. Discussion

The concept and use of DTs have come a long way since the technology was first developed. Beginning as a NASA tool to create models of space capsules, the technology soon expanded to digital simulation to predict how an object, technology, product, or human (consumers) would operate physically and mentally. In this paper, we show how diverse are ad data which are based on many different monitoring devices and technologies generating very large homogeneous, and fragmented data sets. The ubiquity of the ADT system demands the integration of collaborative, adaptive, and interactive components. ADT as a data fusion technology is proposed as a system able to integrate all different kinds of heterogeneous data and models. ADT can serve as a platform in which a combination of different embedded technologies, including IoT, AI, Big Data, and cloud and fog computing, will be used to collect and process data and design models, integration, and interactions, tailored for specificcampaigns, providing bi-directional data linkage between the physical and digital world. This combination of technical solutions will create, in our view, a truly complete picture of the monitored ads, in contrast to common standalone solutions. Thus, the virtual mirror enables an understanding of an ad as more than the sum of its digital representations. The integration of an audience-centric element into an ADT means that the impact of even small changes in consumers' perceptionsand data can be assessed much sooner and without the need for survey research. Such an ADT will constitute a dynamic digital simulation model of the ad, which updates and changes constantly over time. Upon becoming available, ADT will allow campaign scenarios to be thoroughly tested to predict performance. Thus, we conceptualize ADT as an integrated and synchronized framework that facilitates the description, prediction, prescription, and visualization of one or more characteristics of an ad or class of ads within a real-world advertising environment.

To facilitate future use of ADT this paper advances a conceptual framework describing the modes, processes, and outcomes involved in the generation of creative ad ideas. The theoretical framework is based on the integration of empirically established frameworks. The adlandscape grows more complex by the day. Consumers' attitudes and preferences change rapidly, new technologies disrupt ad and media models, and competition reaches new heights. With pressure on managers and ad agencies to continually adapt and optimize ad opportunities to gain a competitive advantage come at a premium. It's in this landscape that the creation of ADTs represents an opportunity to unlock significant new opportunities for ad management, especially when teamed with the appropriate design and creative models. With ADTs, audience behavior and emotions can be monitored through their online personas or avatars in digital programs and social media. While they represent limited information about a consumer's avatars will likely become an important element to adsin the future through the further development of sophisticated digital technologies. Guided by the conceptual framework a systematic expression of the components, behaviors, and rules of the ADT for ad performances was formulated thus, providing valuable theoretical and practical implications and new research avenues for the ad industry and academia.

20. Theoretical Implications

"Digitaltwinsarenotjustafleetingtrendbutanessential component of sustainable innovation"(Stacchio et al., 2022, p.498).

The development and utilization of ADTs will require collaboration across different disciplines, including advertising, marketing, consumer behavior, data science, computer science, design concepts, and domain-specific fields. This interdisciplinary collaboration can foster innovation and knowledge exchange.The proposed ADTaccommodates existingconcepts such as ad templates, divergent ad design thinking, and IMC but also extends current conceptualizations of creativity. Indeed, while the template approach developed by Goldenberg et al (1999) does not explicitly consider the possibility of transformational creativity or template evolution, possibly because it does not take a longitudinal perspective, the ADT framework integrates both processes (generate) and outcome (test) perspectives of ad creativity. The digital representations of physical objects or systems are expected to rapidly transform the ad industry, and their theoretical implications are vast and still being explored. ADTs challenge the traditional understanding of the relationship between the physical and digital worlds. But, they might blur the lines between the real and the simulated, raising questions about the nature of reality and representation. What does it mean for something to be a "real ad" if it has a perfect digital counterpart? (Wang et al., 2024). By creating and designing a dynamic copy of a physical entity like an ad. ADTs can introduce new properties that don't exist in the real ad. This raises theoretical questions about the ontological status of these properties and their implications for understanding the ad world. As ADTs become more sophisticated, they may be able to make decisions and take actions on their own. This raises questions about the nature of advertisers and ad agency and responsibility. Who is responsible for the outcomes and recommendations by anADT? As this technology continues to develop we can expect even more profound theoretical questions to emerge about the understanding of the AI and virtual space and the role of the different stakeholders in it. As Gotz et al., (2022) suggested that there is a significant potential to holistically approach future digitization initiatives with blockchain-based DTs, as well as the positioning of the concept as both a strategic tool and a multifunctional on field support applications. Recent advances in Fog Computing in marketing (Hornik et a., 2023) will assist in moving ADTs processing power and data storage away from centralized server and into local networks where MIoT devices and other monitors are located. Text-to-image diffusion models will achieve a remarkable leap in capabilities over the last few years, enabling high-quality and diverse synthesis of images generation model based on text prompts written in natural language (Alhabeeb and Al-Shargabi, 2024). Inspired by the recent progress of computer vision and natural language processing, Yu et al., (2023) proposed a general text-to-image retrieval for advertising (TIRA) model. Also, the advent of Extended Reality (XR; Stacchio et al., 2022), which is an umbrella term that encompasses various immersive technologies that blend the physical and digital worlds, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), new theoretical issues might emerge. For example, XR might create a hybrid environment where real and virtual ads coexist and interact with each other. For example, an MR application could allow consumers to place virtual furniture adsin their real homes to see how it would look before they buy it.These technologies will provide users with interactive experiences by integrating digital content into their real-world environment or by immersing them entirely into a simulated environment.

20.1 Managerial Applications

*Digital twins have revolutionized film and television production by enabling virtual production and set design. Filmmakers can use digital replicas of physical sets, offering cost savings, flexibility, and the creation of immersive environments. Productions like "The Mandalorian" have exemplified the benefits of this approach, where virtual sets reduce the need for expensive physical sets and streamline the production process (*Grubel et al., 2021, p.2016).

From a managerial perspective, the study results are also novel, as practitioners have just begun to employ DTs. ADT can enhance the process of developing new versions of ads by digitally creating new designs rapidly. A designer can generate ad designs from scratch or generate variations on an existing design. The ADT analysis in this paper and several real-life applications conducted in related disciplines indicate that the ADT is a trainable, resource-saving, and effective tool. It simplifies and improves the decision-making process involved in designing ads and IMC. It can be applied either by hiring trained personnel employed by consulting firms, or by training the agency's own personnel to routinely evaluate past and current ads, and engage in creative activity (Othman 2017).Overall, ADT can offer advertisers a powerful tool for creating more effective and engaging advertising campaigns by harnessing the power of data, models, and automation to deliver more creative, personalized, and relevant ad experiences to consumers (Smolinski et al., 2023) In fact, training individuals in ADT may result in higher levels of "creative expertise". Hence, ad managers are well advised to prepare for challenges and opportunities connected to this transformation. Apart from employing ADTs as additional ad design system, managers might also turn towards this technology to develop it as a decision support tool for improving other advertising campaign elements. For example, managers commonly conduct pretesting in a laboratory setting with high-cost methods such as electroencephalography, Single Source Data, Starch ad recognition, eye-tracking technology, and facial expressions. Comparatively, ADT has two advantages over traditional pretesting.First, ADT allows advertisers to unobtrusively test real market responses from real customers. The test results have strong external validity and robustness. Second, it is a low-cost testing method(Kalantari et al., 2022). Outputsgenerated by ADTs will allow visualization of critical ads information through whichmanagers can more easily identify barriers, evaluate opportunities, and explore outcomes arising frompursuing different creative and strategic paths. Also, ADTs will allow managers the opportunity to move to a predictive maintenance model that strikes a balance between corrective maintenance (post-tests, rectifying poor ad elements) and preventive maintenance (pre-tests, redesigning ads before broadcasting). With ADT devices, the system can detect outliers and errors. Thus, managers can detect problems before they have damaging impacts. By creating a virtual replica of the ad, managers will be able to simulate and test various scenarios before implementing them in the real marketplace.They allow managers to test different scenarios and strategies without incurring the costs and risks associated with implementing changes in the real ad. ADTs will indicate decreasing viewing intensity, signaling to management that diversification or ad modification is necessary.Thus, by ADTs, advertisers can shift fromsubjective, gut feel based thinking to a more objective evidence-based decision-making. The list of applications presented here is not exhaustive, but it demonstrates the usefulness of ADT and the appropriateness of its integration foundation. However, to fully benefit from its strengths and overcome some of its shortcomings, managers should attend to a list of challenges, the most pressing of which are elaborated in the following sections.

20.2 Paper Limitations

Although the use of theory is beneficial in developing ADTs for research applications, it is important to highlight the drawbacks. For example, it is important to acknowledge that although there is extensive theoretical and empirical support for the use of the two underlying ADT models, there is paucity in the discussion of consumers' behavior theories or models that can provide the basis for more advanced ADT applications. Compared to other consumers' behavior influencers, ad design studies lack of rigorous, high-quality evidence on the efficacy and effectiveness of such influencers (Duan et al., 2018; Holberger et al., 2020; Park et al., 2024). To date, few studies of ad elements have specified how their characteristics map onto underlying evidence-based theories and techniques. The current evidence around the effectiveness of digital devices as a consumer monitor tool is limited. Thus, AI-enabled DT is still in its nascent stage, and many research questions remain unanswered.

20.3 Future research

In general, the digital twin is of the enormous potential to innovate traditional disciplines, empower emerging ones, and boost the research in highly sophisticated ones" (Wang et al., 2024, p.107).

Several avenues for future research have merit. For instance,the biggest challenge in developing anADT is the evaluation (testing), particularly assessing the value of novelty and creativity of new ads ideas. All pertinent data from testing should be added to the ADT knowledge database to be used for future evaluations. As the DT technology is still evolving, ad and IMC case study research might provide insights into the benefits and dos and don'ts in ad design. This kind of study might elucidate effect sizes for identified variables which might help to develop first ADT system and of how DT applications affect ad-relevant features, appeals and factors. Also, moderator and mediator variables need to be investigated to refine the cause-and-effect in the ADT framework. Effects and interrelations with overall communication and ad objectives might be in value here, too. The ever-evolving landscape of technology necessitates continual research to enhance and perfect the presented solution, such as improving emotion recognition by facial expressions and speech tone analysis or increasing the accuracy of mental assessment by the current AI model (Smolinski et al., 2023). Another important research requirement arises from the behavioral perspective that has been noted throughout this paper (Wu and Wen, 2021). Interesting insights from ADT studies might reveal why consumers do not like a specific ad or element in the ad (Zhang et al., 2024). These can be explored using ADT with the possible aid of neuro-advertising techniques. We suggest more research issuesin Web Appendix3.

20.4 Final remarks

A team of computational and clinical researchers from Johns Hopkins University has recently developed a *genotype-specific digital-twin' strategy, nicknamed Geno-DT, to create a virtual replica of a patient's heart. "Our novel Geno-DT approach has the potential to augment therapeutic precision in the clinical setting and lead to more personalized treatment strategies in genetic cardiac disease*" (Attaranet al., 2024,p.101).

The DT technology has already proved to be very beneficial in many domains and is gaining wide adoption by companies worldwide. The potential of the ADT is such that its integration and deployment in smart ecosystems for the benefit of ad experts and decision-makers is becoming a necessity.The advancements of Big Data Analytics, AI, and MIoT paved the way to the emergence and use of the 5D-DTs as a framework to twin the life of a physical entity. At the same time, the advent of computerized design theories and models and the HITL conceptprovided us with a unique opportunity to offer a novel conceptual paradigm that may be applied to ad designs. The proposed ADT paradigm is a hybrid approach that combines various modeling approaches with the versatility of data-driven approaches. The framework offers a novel theoretical understanding and practical applications of the mechanisms by which ADT can assist ad design and testing. Determining the proper ad features and layout for a specific campaign is a challenging task, as it often requires dealing with conflicting scenarios and perspectives: human and nonhuman needs, design models, media, competitive considerations, environmental conditions, and costs. ADT is a promising technology for supporting the design, development, testing,and simulation of ads, as well as of analyzing possible ad and IMC effects considering different scenarios (Patti et al., 2015). Thus, ADT can play a vital role in simplifying the design processes by employing digital prototyping, testing simulation, and prediction with many potential design applications. Some challenges and potential development are also discussed. To the best of our knowledge, this is the first work on DT in advertising and marketing. We expect that our work will impact both upcoming research on this excitingtopic, and the development of novel designed and creative ads.

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Web Appendices

Web Appendix 1: More on DTs

A digital twin is a virtual representation of a real-world entity or a system; in other words, a counterpart of a physical object or a process powered by technologies like machine learning (ML), the Internet of Things (IoT), and analytics. When developing expensive hardware (cellphones, cars, fighter jets) or software, a virtual model enables virtual collaboration, simulation, or data acquisition for better iterative design. It helps one understand the system's performance and behavior in a real-world scenario. The virtual replication supplies the answers to the "what if" questions without breaking the prototype. One of the main advantages of a digital twin is that the physical system and its digital twin can co-exist, communicate, and use real-life data from the physical system to improve the simulation. Digital twins are used across industries in several ways. For example, healthcare utilizes this capability for clinical diagnoses, learning, and training, while sectors such as automotive use it to optimize the manufacturing value chain, supply chain, product innovation, and enhancements.

An integrated emulation and prototyping solution can maintain the design integrity that enables iterative and simultaneous verification, and handle tasks of varied sizes and execution lengths, from smaller IP blocks to subsystems up to the SoC and system level. It is also essential to extend this verification effort across the enterprise to other designs being developed concurrently. When managing multiple SoC design projects, it is critical to have a platform that bridges the verification productivity gap to accelerate the verification of SoCs, subsystems, IP blocks, and system-level validation. Likewise, it is important to take a holistic view of the parameters when evaluating emulation throughput. Using a digital twin allows one to verify a chip and the software on that chip. The combined use of Dynamic Duo emulation and prototyping platforms enables one to transition quickly and effortlessly from debugging a chip on the emulation platform to debugging the software running on that chip with the prototyping platform. Digital twins play a crucial role in redefining the emulation architecture with microprocessor-based technology. With digital twin deployments, customers immediately realize improved access to data. As a digital twin matures, other benefits include reduced maintenance costs, more informed process change decisions with large potential savings, and improvements in maintenance and operational efficiency. Having better designs from the start pays dividends over a project's lifetime, as 80–90% of costs incurred during the production, use, and maintenance of a facility are determined at the design stage. Using digital twins in marketing can improve multiuser collaboration and communication. The ability to interact with data in real time is transforming the way marketing makes decisions. The power to visualize and simulate complex operations in real-time 3D has elevated how people interact with their assets, revolutionizing the way every physical space and asset on the planet is created, built, and operated.

ADT. ADT refers to a virtual representation or model of an ad incorporating various aspects of its physical, design, and behavioral characteristics. This concept is part of the broader trend of creating human digital twins, which are virtual replicas of real-world entities or systems. The goal of an ADT is to simulate and analyze different facets of a consumer's life, such as their product use, health, behavior, and personal preferences. This can be achieved by collecting and integrating data from various sources, including wearable devices, health records, social media activity, and more.

Webappendix2: Ad Design Models, Software, and Technologies

Typography. Typography, which includes choice of fonts, text size, and text arrangement, is a crucial element in advertising design. Typography contributes to the readability and overall aesthetic of the ad, helping to communicate the message effectively.

Layout and Balance. Layout, which refers to the arrangement of visual and textual elements on the page or screen, is another important aspect of advertising design. A well-planned layout guides the viewer's eye and ensures a logical flow of information. A harmonious balance is achieved in the layout by distributing visual elements more evenly. Balance ensures that the design feels stable and visually appealing.

Contrast. Contrast helps to make important elements stand out. Contrast in color, size, or style can draw attention to key information and create visual interest.

Branding. Establishing consistent branding elements, such as logos, taglines, and brand colors, is essential for reinforcing brand identity and making advertisements recognizable to target audiences.

Message Clarity. Clarity is paramount in advertising design. The visual and textual elements should work together to communicate the intended message clearly and persuasively.

Target Audience Considerations. Effective advertising design takes into account the preferences, interests, and demographics of the target audience. Understanding the audience aids increating designs that resonate with it.

Platform Specificity. Design considerations may vary based on the platform on which the advertisement is to be displayed, such as print, digital, or social media.

White Space. Adequate white space around elements helps improve readability, clarity, and overall aesthetics.

Fractals. Alsoworth mentioning is the concept of fractals, patterns that repeat infinitely, whichhave inspired creative works, and whose intricate patterns can be generated and visualized through computer algorithms.

Shape Grammars. Likewise, shape grammarare concepts in the field of computer science, architecture, and design, thatprovidesystematic ways to describe and generate complex structures or shapes.

Visual Communication. The aim of visual communication, often referred to as graphic design, is to successfully transmit messages through the use of graphics and other visual forms. With the advancements of 3D software, first, and the modern BIM (building information modeling) software, later, professionals have been able to integrate much more information in digital ads.

ADT. A digital model created following BIM principles is one of the two main inputs in the creation of the ADT, the other being live data captured by the real ad. Various AI-related tools currently are being used the ad industryfor prospecting (*e.g.*, 6sense.com), data management and customer engagement (*e.g.*, segment.com), copywriting (*e.g.*, Jasper.ai, Writer.com), SEO (*e.g.*, SurferSEO.com, Headlime.com, Semrush.com), chatbots (*e.g.*, Chatfuel.com, Drift.com), digital ad personalization and optimization (*e.g.*, albert.ai), media monitoring and competitive intelligence (*e.g.*, Brand24.com, Crayon.co), influencer selection (*e.g.*, influencity.com), social media engagement (*e.g.*, Manychat.com), PR campaigns (*e.g.*, Howler.media), social media content creation (*e.g.*, predis.ai, Flick social), visuals (*e.g.*, DALL-E 2, DreamStudio.ai, midjourney.com), and, of course, dedicated tasks related to advertising (*e.g.*, ChatGPT).

Graphics Processing Unit (GPU). GPUs are crucial for handling graphic-intensive tasks, such as rendering high-resolution images.

Graphic Design Software. Adobe Creative Cloud (Photoshop, Illustrator, InDesign) software is used widely in advertising for image editing, vector graphics design, and layout design.CorelDRAW is a vector graphics editor for illustrations and page layout. Sketch is a vector graphics editor specifically designed for digital design.

Web Design Tools. Adobe XD and Figma are used for designing web and digital advertising materials, including banners, websites, and interactive content. Among prototyping tools, the most widely used are In Vision and Marvel. These help create interactive prototypes of digital advertisements.

Color Calibration Tools. Tools and devices for color calibration ensure consistent and accurate color representation across various displays and print materials.

Digital Asset Management (DAM) Systems. DAM platforms such as Widen and Adobe Experience Manager are used for organizing, storing, and managing digital assets, such as images, videos, and design files.

Project Management and Collaboration Tools. Trello, Asana, and Slack are platforms that aid in project management, communication, and collaboration within advertising teams.

Stock Photo and Video Libraries. Adobe Stock, Shutterstock, Unsplash, Getty Images and more provide access to high-quality images for use in ads.

Cloud Storage and Backup Solutions. Cloud storage platforms such as Google Drive, Dropbox, and Microsoft OneDriveensure secure storage, easy access, and collaboration on design files.

Typography Tools. Topography platforms such as Google Fonts and Adobe Typekit provide access a wide variety of font for use in ads.

Data Visualization Tools. Data visualization tools such as Tableau and Infogram are useful for creating visually appealing data-driven ads.

Additional Computerized Design Models and Systems. Notable additional computerized design systems include Graphical User Interface (GUI) and Natural User Interface (NUI). NUIis based on generative AI and is employed in designing animated advertising to enhance mental imagesallowing for smoother interactions and providing innovative forms of designs.

Another design model is Torrance's Assessment for Creative Thinking in Advertising Design, which cites five dimensions in creativity assessment: (1) fluency, which refers to the number of relevant ideas proposed in response to a given question (such as "list as many use as you can for a paper clip"), (2) originality, which measures how uncommon or unique responses are; (3) elaboration, refers to the amount of detail given in a response; (4) abstractness, which measures the degree to which a slogan or a word moves beyond being a label for something concrete; and (5) resistance to premature closure, which measures the ability to consider a variety of factors when processing information.

Deep Neural Networks. Gatys et al. [2016] recently introduced the Deep Neural Network (DNN) model as an image transformation approach. Briefly, DNN is a network layer of many small computational units. In each layer, the units are considered image filters which extract certain features from the input image. A DNN processes the visual information in a feed-forward manner hierarchically. The output of the network may be a feature ad.

Deep Learning. Notably, the aforementioned design-enabling models are equipped with an AI tool, such as a constraint solver, which can extract the constraints used by designers, or deep learning techniques that can learn from elicited sample designs (dashed arrows). Advertisers' guidelines (rules) involve fundamental visual elements. Deep learning methods, such as CNN, Deep Belief Network (DBN), and Sparse Auto Encoder are structured to detect shapes or contours from design samples. Based on the extracted ads, this step could formulate new elements. Color features, in turn, may be learned from the samples to modify existing coloring rules or generate new rules. Thus, more concrete rules potentially can be automatically learnt. These automatically-modified design rules may or may not be further refined before another round of automatic design generation. Like generative art, generative ads can include fractal art and abstract ads generated from existing designs, both of which can generate distinctive ads although they may use different methods.

After selecting and measuring appropriate features, the next step is combining elements and aesthetic scores for overall evaluation. There are several types of evaluation methods, including binary classification and rating. A binary method classifies ads, for instance, into beautiful and unbeautiful. A rating method scores ads according to their appeal, typically from1to10. The recognition approach (Starch method) involves experimenting with different design elements and layouts through A/B testing. This involves creating multiple versions of an advertisement to determine which designs resonate best with target audiences.

Programmatic Creative. Programmatic creative refers to the use of technology and data to automate the process of generating and optimizing digital advertising creative elements, such as images, videos, and copy, in real-time based on user data, context, and other relevant factors. It uses creative optimization techniques to deliver more personalized and effective advertising messages to target audiences. "The purpose of programmatic creative is to enable data and creativity to come together to tell brand stories in a more resonant and effective way than ever before" (Hornik et al, 2017,p 44). The most often cited use of programmatic creative is to personalize ads in such a way as to be more relevant to their audiences. Instead of showing one generalized creative to all, it is now possible to segment audiences into groups and show each group a custom creative that is more likely to impact them specifically. Programmatic creative also enables better message testing and optimization, by both enabling the creation of multiple ads for testing purposes and potentially automating the test to optimize on its own. Thus, in essence, programmatic creative allows designers to quickly turn around a high volume of quality ads, match them to specific audiences, and take action based on the results. This is possible largely through computer-enabled workflows, software automation, and big data integration.

Web Appendix 3:Further Questions to Be Explored in Future Research

What possibilities exist for how ADT can be harnessed by advertisers? Where are advertisers likely to see the most effective use of ADT?

How might advertising research evolve due to new ADT research tools? Can they replace or merely augment human efforts?

To what extent are consumers aware of and knowledgeable about DT practices in the content they view? What factors influence audience experience and trust in viewing ADT-generated content? How do consumers react to ADT mimicking human behaviors?

How can ADT be used in experimentation, such as A/B ad testing?

- When and how are ADT tools best used to create visuals and copy in advertisements? How do consumers respond to ads created using ADTand why? Do consumers respond differently to certain types of ads and, if so, why?
- ADT has the potential to create very personalized ads targeting micro-segments or even individual consumers. How will consumers respond to such ads? When and why might consumers like vs. resist such personalization?
- ADT makes it possible to alter the characteristics of models in ads to increase diversity. For instance, it can be used to change colors, ethnicity, age, and gender. How do consumers respond to such virtual diversity?
- How can advertisers respond to the threat of components of their ads being copied, altered, or used by others? To what extent should brands use material (i.e., images, text) and ideas from others when creating and using ADTs?
- What factors will affect advertisers' and agencies' adoption of ADT and what risks do advertisers and agencies need to be aware of and mitigate to ensure its effective use?
- What are the possible implications of human-ADT (human-machine) interactions?
- What ethical considerations do advertisers need to be aware of (e.g., algorithm bias) when utilizing ADTs, and what consequences exist for diversity, equity, and inclusion (DEI)? What implications does this have for the governance of DT to ensure a responsible and ethical approach to use?