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# Adaptive Systems for Internet-Delivered Psychological Treatments

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**ABSTRACT** Internet-Delivered Psychological Treatments (IDPT) are based on evidence-based psychological treatment models adjusted for interaction through the Internet. The use of Internet technologies has the potential to increase the availability of evidence-based mental health services for a far-reaching population with the use of fewer resources. Despite evidence that Internet Interventions can be effective means in mental health morbidities, most current IDPT systems are tunnel-based, inflexible, and non-interoperable. Hence it becomes essential to understand which elements of an Internet intervention contribute to effectiveness and treatment outcomes. By analogy, adaptation is a central aspect of successful face-to-face mental health therapy. Adaptability to patient needs can be regarded as an essential outcome factor in online systems for mental health interventions as well. While some aspects of rule-based and machine-learning-based adaptation have attracted attention in recent IDPT development, systematic reporting of core components, dimensions of adaptiveness, information architecture, and strategies for adaptation in the IDPT system are still lacking. To bridge this gap, we propose a model that shows how adaptive systems are represented in classical control theory and discuss how the model can be used to specify adaptive IDPT systems. Concerning the reference model, we outline the core components of adaptive IDPT systems, the main adaptive elements, dimensions of adaptiveness, information architecture applied to adaptive systems, and strategies used in the adaptation process. We also provide comprehensive guidelines on how to develop an adaptive IDPT system based on the Person-Based Approach.

**INDEX TERMS** Adaptive systems, Internet delivered psychological treatments, person based approach, information architecture, personalized Internet interventions, tailored Internet interventions, ICBT.

## I. INTRODUCTION

In face-to-face therapy for mental health, therapists adapt their behavior towards their patients, to ensure the highest likelihood of successful therapeutic outcomes. The therapist's behavior is partly dynamic and can change in response to the patient's development. In Cognitive Behavioural Therapy (CBT) for social anxiety and fear of public speaking, for example, the therapist will begin with helping the patient to become comfortable with one particular social space. Once the patient is comfortable with that space, the therapist will adapt and help the patient generalize the progress and become comfortable in a broader range of social settings. In the case of reversal of development, the therapist will return to focusing on tasks previously managed by the patient. The therapeutic goals, dynamic guidance from the therapists, and the feedback that the patients experience with the therapists are essential outcome factors for mental health therapy.

Currently, online systems for mental health therapy are becoming widely available. Human beings are adept at understanding and communicating with others, and creating interpersonal contexts that are conducive to reaching a predetermined goal. These conditions are more challenging to re-create in online environments, however. It requires the re-alignment of roles, activities, and the remediation of information and intervention materials. While it is impossible to

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emulate face-to-face therapy in online settings completely, and online interventions are therapeutic constructions in their own right, one measure to help to ensure successful therapeutic outcomes is to make the environment adaptive to the user.

Building Adaptive Internet-Delivered Psychological Treatments (IDPT) requires input and competencies from both computer science and psychology, each presenting different challenges to building an adaptive system. From the computer science perspective, one challenge lies in the perpetual evolution of software systems and the integration of technology. As a result of this continuous evolution, software systems must be versatile, flexible, resilient, dependable, robust, energy-efficient, recoverable, configurable, customizable, and self-optimizing by adapting to operational changes in contexts, environments and system characteristics [1]. Additionally, the complexity and uncertainties of the problems arising in software systems are dynamic. These complexities prevent the use of a common *a priori* solution. Instead, an endeavor is made to solve this problem adaptively by dynamically collecting information about the problem at hand and using this information to generate an acceptable solution [2]. From the psychotherapy perspective, the ideal mental health treatment administered to one patient is not necessarily the same as that given to another patient exhibiting similar symptoms [3]. The individual nature of mental health problems makes it difficult to successfully make technology that resonates with human behavior and creates positive outcomes. People with similar mental health problems require different kinds of treatment. So, the technological solution needs to be adaptive to disseminate personalized treatments.

The Person-Based Approach (PBA) is a development methodology aimed at overcoming both Information and Communications Technology (ICT)-related and human-related challenges to build successful interventions for people to manage their health or illness [4]. PBA is explicitly developed for mental health interventions and health management and is meant to complement evidence, and theory-based treatment approaches by capturing and incorporating user perspectives in the design process [5]. PBA draws on methods from user-centered design [6], particularly behavioral analysis, and in-depth qualitative research [5], and seeks to understand both digital and non-digital behavioral aspects of interventions [7]. For mental health interventions to be effective, they must have a positive effect on the quality of life of the patient, they have to be technologically robust, flexible, and evidence-based, and they must have taken user interaction and engagement into account. Through building knowledge about user views, context and experience, the goal is to create interventions that are ''maximally meaningful, feasible and engaging for all users'' [7, p. 464], and ultimately to ensure the effectiveness of the intervention [5]. In this study, we further bridge the gap between approaches for participatory/user-centered and systems architecture design by adapting and expanding PBA to provide guidelines to build successful *adaptive* IDPT interventions. Adaptive systems for mental health therapy and PBA combine well, as both share the aim of increasing the usefulness for and relevance to the user. Furthermore, successful implementation of online mental health interventions requires the combination of several perspectives, including computer science and behavioral science. Hence, we consider the main contribution of our study to be a conceptual framework combining the systemic approach of model-driven software development of adaptive systems supporting online mental health therapy, with the empirically driven design framework of PBA. Both perspectives share the goal of facilitating the highest possible use of digital mental health interventions. We furthermore envisage that the resulting framework will allow developers, designers and researchers to reuse the same intervention system for multiple mental health issues.

We have tabulated a list of related works in Table 2 and compared them with our work in Section IX. To summarise, although some studies attempted to personalize interventions using the rule-based method and machine learning methods, none of the studies, to our knowledge, reported a reference model of an adaptive system and its core components systematically. We aim to fulfill this gap by proposing a reference model and outlining its core components.

The contributions of this study are the following:

- First, we propose a model that shows how adaptive systems are represented in classical control theory and show how the model can be used to specify adaptive IDPT systems. Moreover, concerning the reference model, we outline the core components of adaptive IDPT systems, the main adaptive elements, dimensions of adaptiveness, information architecture applied in adaptive systems, and finally, several strategies used in the adaptation process.
- Second, we provide comprehensive guidelines on how to develop an adaptive IDPT system building on the Person-Based Approach.

The rest of the paper is structured as follows: Section II outlines a definition of adaptive systems. Section III discusses adaptive IDPT systems and their types. Section IV describes several dimensions of adaptive IDPT systems. Section V outlines elements that can be adapted in an IDPT systems. Section VI describes different information architectures that can be observed in IDPT systems. Section VII outlines strategies that are used in the adaptation of IDPT systems. Section IX outlines a list of related work where we compare and relate our work with previous studies. Finally, Section VIII provides a guideline on how to develop an adaptive IDPT system with respect to the Person-Based Approach.

## II. ADAPTIVE SYSTEMS

An *adaptive system* is a set of interacting or interdependent entities, real or abstract, forming an integrated system that changes its behavior in response to its environmental changes [8], [9]. The changes that occur in its behavior are relevant and directed towards the fulfillment of the

**TABLE 1.** Different dimensions of adaptive Internet delivered interventions.

| Dimension | Descriptions |
|---|---|
| User preferences | Temporal preferences, content presentation preferences, lingual preferences, based on interaction log analysis |
| Goals of the interventions | Therapists oriented goals, patient-centric goals, which are characterised by evolution, flexibility, duration, multiplicity and dependencies. |
| Measures | *Psychometric tests*: (Depression (MADRAS, MDI, BDI), Generalized Anxiety Disorder (GAD-7), Bipolar Disorder (Altman Self-Rating Mania Scale), ADHD (Adult ADHD Self-Report Scale) and others.), *user behavior analysis based on interaction data* |
| Adaption actor | Automatic, semi-automatic (algorithm + therapist) and manual (Therapist/Users) |
| Adaptation strategies | Rule-based, Goal-based, Machine Learning-based, Hybrid approach |

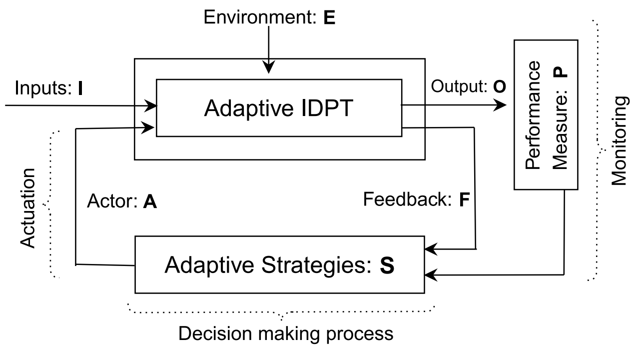


**FIGURE 1.** We propose an Adaptive IDPT model based on classical control theory. It illustrates IDPT systems as a complex function that works in an environment (E), consumes controlled inputs (I), generates outputs (O). The system measures the performance of the outputs using some measures (P) and uses some feedback function (F) to create adaptive strategies (S). Actors (A) trigger the adaptation. These strategies control how the IDPT system should adapt.

objectives defined for the system. Self-adaptive software is context-dependent and has the ability to modify its structure and behavior in response to the contextual changes. This kind of software provides the users with context-dependent functionalities (presenting users with correct lingual interventions based on the country, for example – if a user is using IDPT system from any particular country, the intervention is presented in the language of that country) and context-independent functionalities (for example login form for authentication and authorization where different users credentials are checked for validity and permission with database). We chose to define adaptive IDPT abstractly, based on literature [10], [11], using classical control theory as illustrated in Figure 1.

The formal representation of the adaptive IDPT system constitutes the following components:

- a set of environments **E** in which IDPT is working as a complex process.
- a set of controlled inputs **I** consumed by IDPT systems for changing the behavior of the process. These inputs can vary from text-based inputs, sensor-based data such as heart rate, electro-dermal activities (EDA), user activities data, sleep data, voice data, eye movement data, and other types of biological markers.
- a process to measure the performance of the system **P** indicating performance of the IDPT in environment **E** when consuming **I** as input. Psychometric tests (see Table 1) are the principal performance measures for IDPT systems.
- a feedback function **F**, which generates an adaptive strategy with dynamic information about the process being controlled.
- a set of strategies **S** (see section VII), which use the knowledge learned from information and performance of the system.
- a set of actors **A** (see Figure 3) who trigger adaptation.

In general, adaptive software systems include monitoring, decision making, and actuation to maintain dependable behavior despite sudden, unpredictable changes like application workload fluctuations and hardware failures. As depicted in Figure 1, a set of inputs is monitored by an adaptive IDPT system to produce some output. Several performance measures, like psychometric tests and goal achievements, are used to evaluate the efficacy of the results (monitoring). Based on these measures, several strategies (decision-making process) are used to change the behavior of the system (actuation).

## III. IDPT SYSTEMS

Internet-Delivered Psychological Treatment (IDPT) systems refer to any software applications that facilitate interaction with psychological therapy through the Internet. These mainly include web-applications, mobile applications, augmented reality, and virtual reality applications. Several terms are used in research to refer to IDPT systems, for example *web-based treatments, web-based interventions, online treatments, computerized psychotherapy, e-therapy, Internet-based cognitive behavioral therapy (ICBT or iCBT), digital interventions, internet-based interventions, online interventions, web-application based psychotherapy treatments, therapeutic web-based interventions, eHealth interventions [12], and others.* In addition to this, researchers use different technical terms to represent the IDPT systems, for example *Interapy* [13], *Deprexis* [14], ULTEMAT [15], dBCIs (digital behaviour change interventions) [16], smartphone-based applications with specific brand names [17]. To be consistent, we chose to use the term

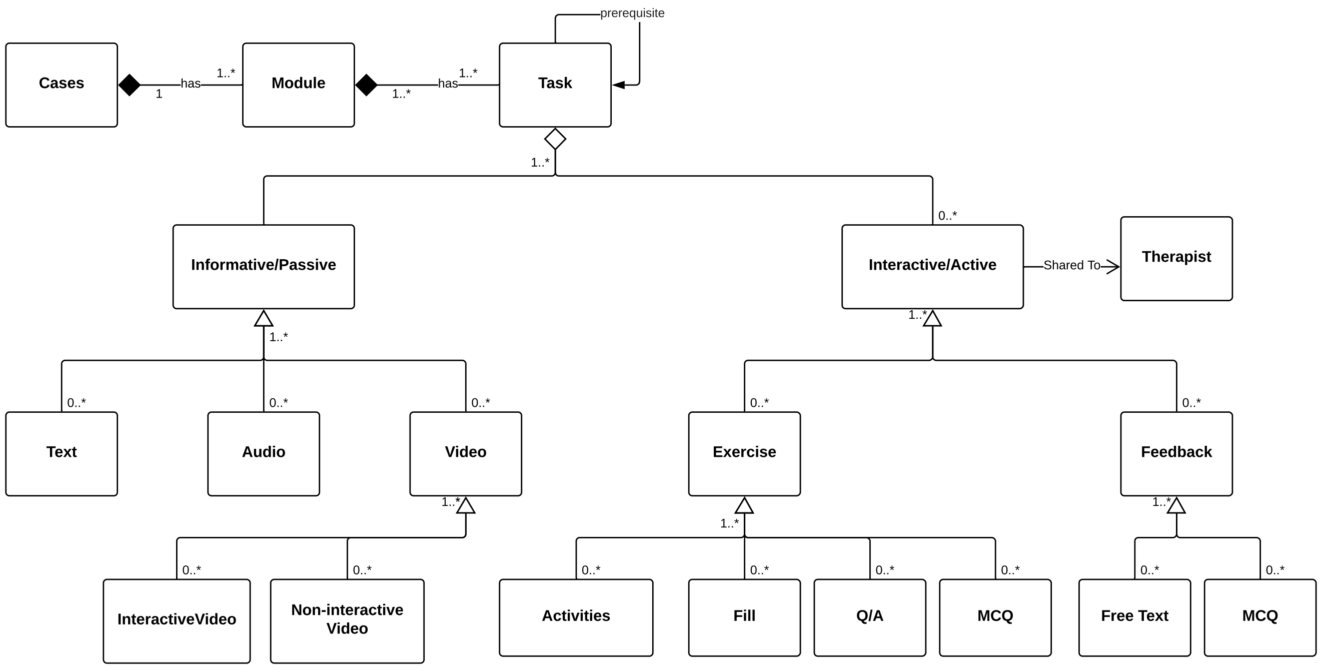


**FIGURE 2.** The conceptual model of Internet-Delivered Psychological Treatments (IDPT) includes one to many cases (Depression, Social Anxiety, and other mental health issues.). Each case contains one to many modules (Sleeping issues, Speaking issues, improving concentration, and others.) Each module, in turn, includes one to many tasks, which has prerequisites as the constraints. Each task contributes to collecting passive or active data in the system. Based on what type of data these tasks can accumulate, they consist of text task, audio task, video, exercises, or feedback.

*Internet Delivered Psychological Treatments*, as suggested by Andersson *et al.* [18].

IDPT has surfaced and grown as one of the most commonly practiced and widely researched forms of psychotherapy [19]. The evolution of IDPT, coupled with the exponential growth of Internet access throughout the world, has the potential to reshape the landscape of mental healthcare. Despite evolution in IDPT, several patients suffering from mental health issues go untreated [20], [21]. Obstacles to receiving treatment for mental health problems include long waiting lists, limited access to psychiatric medications, perceived stigma of seeking help, and treatment costs [21]–[23]. IDPT systems have been proposed as one solution to bridge this treatment gap. IDPT removes several barriers over traditional face-to-face therapy that hinders the majority of patients from efficient psychiatric care [24]. The use of IDPT tools can enhance patient health in several ways: 1) IDPT can be available and accessible from anywhere with an Internet connection [3]; 2) the temporal aspects of access can be substantially improved; 3) the scalability of IDPT can drastically enhance the functional capacity of the care; 4) makes the treatment cost-effective for individuals who do not have insurance or can not afford the out-of-pocket fees for treatment, and 5) removes the discomfort and the stigma related issues associated with the face-to-face approaches.

### A. COMPONENTS OF IDPT

Figure 2 depicts a conceptual model of IDPT. A typical IDPT contains several components:

- **Cases**: Typically, IDPT includes one or more cases such as Depression, Social Anxiety, Bipolar Disorder, ADHD, and other mental health issues [25].
- **Modules**: Each case contains one to many modules that focus on any particular dimension of the case. For example, for depression, there can be a module for sleeping issues, concentration issues, speaking issues, and others. One module can belong to one or many cases. The modules can have dependencies.
- **Tasks**: Each module, in turn, includes one to many tasks and have constraints as the prerequisites. Examples of such constraints include task dependencies, task availability, publication date, and others. Each task contributes to collecting passive (informative) or active (interactive) data in the system. *Informative tasks* provide learning materials about the mental health issue (case), symptoms, use cases, and several ways to manage them. The main objective of such educational materials is to provide psycho-education so that a) patients and their families can learn about symptoms, causes, and treatment concepts; b) patients can comprehend self-help program and steps required to manage their illness; c) patients can correlate their situations with similar others which helps to ventilate their frustrations. Such educational materials are in the form of reading tasks (text), listening (audio), and watching (video). In contrast to informative tasks, *interactive tasks* involve user interactions and often in the form of exercises. The exercises can be physical activities or computerized

tasks. Examples of activities include physical workouts and mindfulness exercises such as breathing exercises, walking certain distances, stretching, or physically performing any other activities. Examples of the computerized exercises involve fill in the blanks, question answering (Q/A), multiple-choice questions (MCQ), and feedback. The feedback type of task consists of using free text, rating systems, or multiple-choice questions.

### B. TYPES OF IDPT

- **Guided vs unguided**: IDPT can be either guided [26] or unguided [27]. In guided IDPT, a therapist is a planned part of the online intervention environment, and available to the patient to some degree. In unguided online therapy, the intervention is automated and independent of human support [28]. Several review studies (e.g., [28], [29]) find that participants in guided online interventions overall benefit more from the intervention compared to unguided interventions. The qualification of the therapist in these settings affects the patient results to a lesser degree [28]. A therapist in guided IDPT can make a diagnosis and determine the suitability of the treatment for a patient. The adherence rates in guided IDPT are also higher [29]. Several authors (e.g., [28], [30], [31]) have also found that the presence of accountable and trusted moderators, for example, enhances participant motivation and adherence in online therapy environments. There are, however, potential reasons for patients to prefer unguided options, such as privacy and increased likelihood of self-disclosure in stigmatic cases, and there are also ways of making unguided online intervention environments adaptive, such as automated notifications [32] and pre-intervention screening and tailoring [33].
- **Personalized care vs. stepped care**: There are two types of mental health care:
  - **Personalized Care:** Personalized medicine in P4 medicine [34] holds a great promise in improving the quality of treatments for mental health conditions [35]. The term P4 medicine stands for **personalized** (the focus of care is on the individual), **predictive** (signs of the illness can be recognized before it manifests), **preventive** (with correct tools and pre-diagnosis, can be prevented), and **participatory** (informed about the health conditions and healthcare decisions). With personalized care, treatment outcomes are improved by giving individual patients a treatment that is precisely right for them [36]. Personalized medicine is usually thought of as a way to match patients to the optimal intervention before initiating treatment [36], [37].
  - *Stepped Care:* In stepped care, all or most of the patients are given the same, least intensive, and most readily available treatment [38]. In stepped care, the treatments initiate with simpler form and are gradually stepped up for those who can not benefit from simpler treatments [38].

## IV. DIMENSIONS OF ADAPTIVE IDPT

The way an adaptive system changes its behavior depends on a multitude of factors: a) users' preferences, b) goals of the interventions, c) measures, d) adaptation actors, and e) adaptation strategies. We refer to these aspects as the *dimensions* of adaptive IDPT. Andersson *et al.* [39] propose a classification of modeling dimensions for the self-adaptive software system. According to the study, the authors distinguish four dimensions of self-adaptive systems: *goals of the system, change that causes adaptation, mechanism which is the reaction of the system towards the change* and finally *effects which is the impact of the adaptation upon the system.* Similar to these dimensions, we propose five distinct dimensions as illustrated in Table 1 in the IDPT systems.

### A. USER PREFERENCES

Most of the mental health interventions have been modeled on a psychological therapy format with variation in the intervention period, content types, mode of delivery, and health issues. In general, the content is structured and designed to allow users to learn and practice new skills that help them to manage their illness. However, Internet content is often not designed in this way. Arguably, this is one of the reasons users spend less than 70 seconds on 80% of IDPT web applications [40]. It is reasonable to infer that users of IDPT have preferences for different models of engagement. User preferences [41] may influence other aspects of design, the modality of content, choice of videos, images, texts, or a combination of these that impact user engagement with online content [42]. User preferences can be the temporal, content presentation, and lingual. In *temporal preferences*, users tend to engage with interventions at different time instances of a day. In the *content presentation preferences*, the contents can vary from texts (reading), audio (listening), videos (watching) and exercises (writing). Users have different preferences regarding the type of content they like to interact with. In the *lingual preferences*, the users prefer to interact with the system in their language.

User preferences can be captured in two ways: explicitly asking and implicitly inferring, by recording the actions of the users as the form of a log. The latter choice is less intrusive. Log analysis helps therapists to understand their patients' preferences on the one hand and shows the bottlenecks in the system on the other. Agosti and Di Nunzio [43] presents a general methodology for gathering and mining information from Weblogs.

### B. GOALS OF THE INTERVENTIONS

Goals are the primary objective of the entities under consideration. Here, we outline two major types of goals: *patients goals* and *therapist goals.* In general, the goal of patients is to learn to manage their illness where the therapists' goal is to increase treatment outcomes so that the patients get better treatments. Goals of IDPT can have the following characteristics:

- Evolution: Goals can change within the intervention lifetime.
- Flexibility: Goals can be flexible in the way they are expressed. For example, *users must complete module one before going to module two* indicates a rigid goal. *A user can choose between assignments from the first module*, indicates an unconstrained goal.
- Duration: Goals of the intervention may hold validity throughout the intervention's lifetime or may be temporary.
- Multiplicity: The number of goals associated with the adaptive aspects of IDPT. An IDPT can have a single goal or multiple goals. Single goal IDPT systems are easier to implement.
- Dependency: In any IDPT system, goals can be related to each other. The goals can be dependent and independent.

### C. MEASURES

As illustrated in Figure 1, an adaptive IDPT system contains a way to capture user behavior. Behavioural data are essential inputs to an IDPT system, to make it possible to adapt to the user in a meaningful way. Several data sources can be used as relevant indicators of patient behavior and symptom development. In guided online interventions, self-assessment using validated screening tools, telephone, video conversations, and written communications can be used. Counselors in guided IDPT also assess written responses to assignments and patient diaries. Additionally, also for non-guided interventions, it is possible to use indicators such as system interaction data to gauge patient engagement with an intervention. The potential of using sensors embedded in smartwatches, mobiles, and other devices has also been explored, for example, to measure physical mobility, sleep patterns, voice, medication adherence, and heart rate variability, to name a few. Here we consider the measures of psychometric tests and user behavior analysis:

- *Psychometric tests*: Psychologists have developed an effort to quantify people's preferences, behavior, and intelligence through self-assessment questionnaires referred to as psychometric tests. For example *PHQ-9 [44], MADRS-S [45], and BDI [46]* is used for assessment of depression. *GAD-7* [47] is used in self-assessment of general anxiety disorder. Scores from these tests can be utilized to adapt the modalities of content.
- *User behavior analysis*: We can analyze user behavior based on the interaction between the user and an adaptive IDPT system to gather user preferences and learn what a user likes the most. These insights can be extracted by analyzing the usage intensity of the system, such as the time a patient spent on watching videos, listening to audios, reading texts, interacting with intervention exercises, and other activities. The analysis of intensity can reveal user preferences and the engagement of the patients [48]. We can use the preferences information to personalize the adaptive elements (see Section V). Moreover, therapists can compare the expected behavior of the user and the actual behavior. This comparison can reveal where the bottlenecks are in the system and guide us to improve the structure of an IDPT system.

### D. ADAPTATION ACTORS

There are three different types of adaptive systems based on the actors involved in triggering adaptation. First, the *automatic systems* that have the capability for self-adaptation. Second, the *semi-automatic systems* where a portion of adaptation is done by algorithms and a portion of adaptation is controlled by the therapists. Finally, *manual systems* where an actor (therapist/medical practitioners/trained medical personnel) manually adapts the interventions in IDPT. The use case diagram, as Figure 3 illustrates different types of actors involved in an adaptive IDPT system. The actors *adaptive systems* and *medical practitioners* are actively involved in the task of triggering/creating an adaptation. The actor *patients* uses the adaptive system, and finally, the actor *IT admin* monitors and maintains the adaptive system to ensure proper functioning. We like to highlight that the use cases functionalities illustrated in Figure 3 provide a generic example and can differ according to the context of the project.

### E. ADAPTIVE STRATEGIES

Adaptive strategies refer to a set of techniques applied to change the behavior of an adaptive system. In Section VII, we outline four different types of adaptive strategies including *rule-based, goal-based, feedback-loop based* and *ML-based* approaches.

## V. ADAPTIVE ELEMENTS: WHAT CAN BE ADAPTED

Having argued for the necessity of adaptation and different dimensions of the adaptive system, in this Section, we identify what can be tailored in IDPT. Although there is no explicit study done, to our knowledge, to categorize what can be adapted, we present a list of elements in IDPT that can be adjusted.

- *Content presentation*: IDPT systems use psycho-education as the primary technique to educate patients on any healthcare problems. To do so, therapists prepare several educational materials such as use cases, events, activities, and physical exercises to familiarize patients with the symptoms of any particular illness. We refer to these educational materials as intervention content. We can present these contents in several modalities (e.g. slides, audio, video, animations, and texts) and layouts in any IDPT system. How we present the content to the user can be adapted based on several dimensions, as shown in Section IV.
- *Information architecture*: Section VI presents four different types of Information Architecture (IA) that can be adapted based on various dimensions.

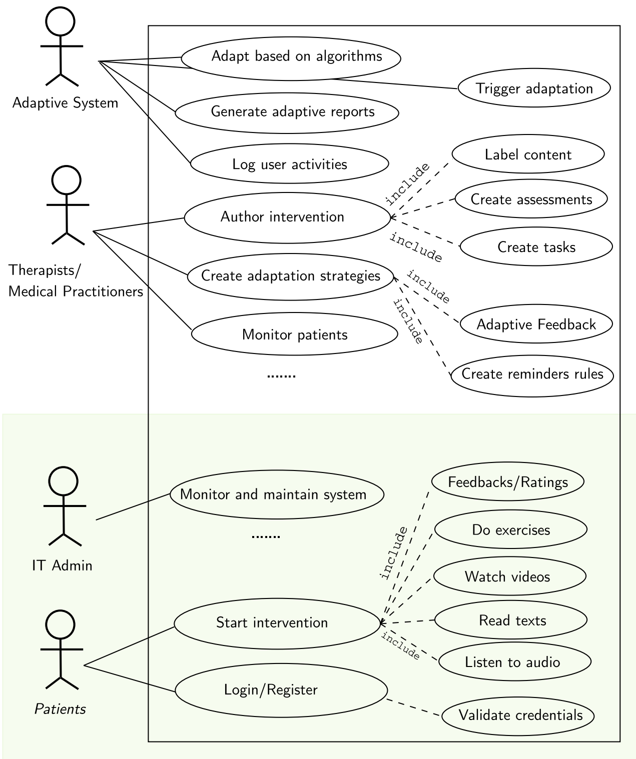


**FIGURE 3.** **The Figure illustrates the different types of actors involved in adaptive IDPT systems. The actors' *adaptive systems* and *medical practitioners* (top block) are actively involved in the task of triggering/creating adaptation. The actor *patients* (bottom block) use the adaptive system, and finally, the actor *IT admin* (bottom block) monitors and maintains the adaptive system to ensure proper functioning. The dots illustrate the actors can perform several other actions defined by the context of any project.**

- *Content complexity*: Content complexity is associated with cognitive demands inferred from the language of a content standard. In essence, content complexity incorporates several factors such as prior knowledge, processing of concepts, skill set, sophistication, application of content structure, number of parts, and length of the content. Because of its dependency on prior knowledge and processing skills that vary between person to person, content complexity adaptation based on several dimensions is essential.
- *Content recommendation*: If an IDPT is recommending content to the participants, it should be adapted based on the user preferences, interests, and other dimensions mentioned in Section IV.
- *User Interface*: Adaptive User Interface (AUI) changes its layouts and its elements according to the need of the user or the context [49]. Often, creating AUI is primarily based on the features of IDPT systems, and the knowledge levels of the users that will use the systems. By making these adaptations, the IDPT systems gain an ability to conform to the users' needs. For example, *adaptive presentation* aims to display certain information based on the current user. If the current user indicates novice knowledge, the system can adapt to display minimal information. Conversely, if a user shows advanced understanding, the system adapts to illustrate with more detailed information. Using adaptive strategies is likely to overwhelm less [50], [51] novice users with complex content. Similarly, *adaptive navigation* intends to guide a user to their specific goal within the system by transforming the way the system is navigated based on certain factors (like goals of the user, previous history information, current skill levels) of the user.
- *Feedback*: Several studies indicate that incorporating feedback mechanisms increases user adherence. Several forms of feedback mechanism has been used including *email, SMS, phone calls, conversational agents (chatbots [41])* and *support forms*. However, there can be several perspectives on how patients perceive feedback. Hence, it should be adapted based on the patients' needs.
- *Notifications/Alerts/reminders*: In an information system, personalized information is sent to patients as reminders, alerts, or notifications. Notification is a technique of bringing something to notice to the users. Reminders are specific types of notifications that are sent to stress about upcoming events. In an IDPT system, reminders have been used to notify clinicians and patients about appointments, screenings, upcoming interventions, tasks, or activities. An alert is a type of indicator such as a badge, sounds, missed required fields, success, or fail messages to inform users that they should look at something. Unlike alerts, a notification is accompanied by more information and is not always in the current task context.
- *Reports*: Reports are reflections of data collected by IDPT that are sent back to the users. Reports may include a subset of visualization techniques conveying specific information generated from the previous state of the users and current assessment. For example, a graph showing the current calorie count of the users, thoughts records.

## VI. INFORMATION ARCHITECTURE OF CURRENT IDPT

Information Architecture (IA) plays a vital role in web application development, and a good architecture can enhance the ability of employees and customers to find information and decrease the application maintenance cost [52]. Despite some recommendations for using Architecture Centric Development (ACD) in behavioral and mental health interventions, there is still a lack of empirical evidence for the role of architecture in IDPT [50]. Current IDPT using ACD primarily focus on navigation systems [53] and their architecture can be *hierarchical, matrix, hybrid* and *tunnel based* [50], [54].

1) **Tunnel design**: 90% of the available IDPT systems use tunnel-based design [55] where users navigate sequentially through the intervention. Tunnel based design is analogous to watching TV, reading textbooks, attending academic classes, or attending multiple clinical sessions. An argument for this model is that a tunnel

design experience is less likely to overwhelm users with information and options [50], [51].

2) **Matrix design**: Matrix IA is designed on the principle of hypertext HTML. In a matrix design, the user can freely pursue their interests by using their path available through information. The designers of matrix IA use several organizational schemes to group the content into several categories. Examples of organizational schemes include alphabetical order, chronological order, topic scheme, and audience scheme. The primary rationale of using the matrix design is to provide maximum information within a system. According to Lynch and Horton [56], matrix design may not be well-suited to helping users to become familiar with new content. However, it is more applicable to web applications that are designed for highly educated and experienced users.
3) **Hierarchical design**: Information is organized in a top-down manner so that users can review specific content in a non-sequential way. The hierarchical design provides a simplified view of the content, making it easy to retrace steps. However, deeply nested information may be difficult to locate [57].
   As outlined in Subsection, III-A, we view an adaptive IDPT to follow the hierarchical Information Architecture. A common representation of the hierarchical IA is in the form of a graph. Here, a graph can illustrate the components of an IDPT system. Formally, we define a graph $G$ as a pair $(V, E)$ where $V$ is a set of vertices, and $E$ is a set of edges between the vertices $E \subseteq (u, v)|u, v \in V$ [58]. The vertices of the graph represent the components of an IDPT system, and the edge represents the constraints. For example, a module in an IDPT system contains several tasks. Each task represents the vertices. A patient must fulfill one or more constraints before we mark the task as completed by the user. We indicate these constraints by edges. For example, task dependencies constraint indicates the patients must complete a certain task before other tasks are available. Formalizing an IDPT system using graph theory is beyond the scope of this paper, and is marked as one of the immediate future work.
4) **Hybrid design**: It is a combination of one or more IA designs that best-fit content and purpose. Several current web application takes advantage of hybrid design [57] as it combines merits from other models.

It is not straightforward to know what components make up an Information Architecture [52] because people directly interact with some components. In contrast, other components are behind the scenes that people are not aware of their existence. In general, any IA consists of four different components:

1) *Organization systems:* It deals with how we categorize the information, such as by subject, by chronological order, by alphabetical order, by geographical order, by audience types, and so on. Organizing information is crucial because it reduces ambiguity in finding information, reduces heterogeneity, and labeling systems are intensely affected by the creators' perspectives. The difference in attitude makes information organization a problematic task.
2) *Labeling systems:* Labeling deals with the form of representation. A label illustrates a chunk of information. For example, Frequently Asked Questions (FAQ) is a label that describes a piece of content that most of the users typically wonder. Labeling is crucial as it 1) communicates with the patients revealing them the essential information, and 2) the interaction data with labels help in using supervised machine learning algorithms [59].
3) *Navigation systems:* It deals with how we allow users to browse or move through the information in a system. The navigation system facilitates browsing and contains several types, such as global navigation, local navigation, and contextual navigation. A global navigation system is present on every page throughout the application. Local navigation helps to browse on a specific page. For example, often, we provide an index of the main sections in any application page. Contextual navigation aids providing contextual navigation links that are specific to any particular piece of information. Such contextual navigations are applicable when we intend to provide extra contextual information if the user intends to. For example, in an adaptive IDPT system, we offer tasks that facilitate psycho-education related to any particular symptoms of mental health. However, we do not discuss in detail about the symptoms. In such a case, we can provide contextual navigation by using a hyperlink that links to a document providing detailed information about the symptoms. Once we design the navigation system, we can adapt these based on the user search behavior. Gobert *et al.* [60] presents SAM, a modular and extensible JavaScript framework for self-adapting menus on the web pages. According to the study, SAM provides a mechanism to self-adapt the navigation systems, which in turn offers personalized web experience.
4) *Searching systems:* It deals with how users search for information. A searching system is a challenging and well-established field on its own. Hence, before investing time and budget on creating a search system, we recommend determining whether the product needs a search system. If we decide to build a search system, then it requires defining the basic anatomy of the search engine, what is searchable, choice of retrieval algorithms, understanding retrieval results, and the search interfaces.

Explaining all the components of IA in depth is beyond the scope of this paper. The book by Morville [52] outlines these components in detail.

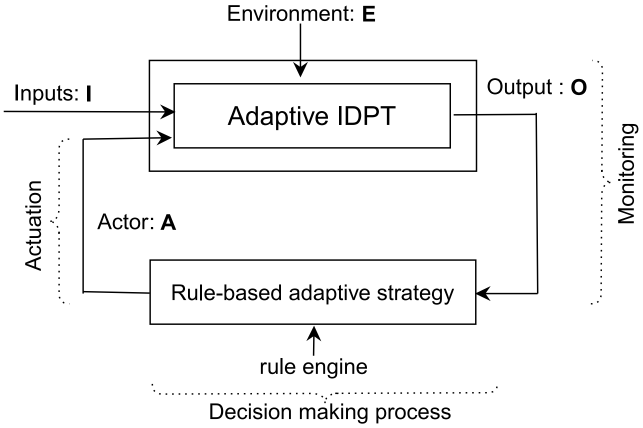


**FIGURE 4.** In a rule-based adaptive strategy, a set of predefined rules (managed by the psychiatrists and referred to as rule engine) modifies the behavior of the system. When these rules are truthy, an adaptive actor triggers the adaptation.

## VII. STRATEGIES FOR ADAPTATION

In the last decade, several strategies for adaptation has been practiced to improve the effectiveness of IDPT, and a multitude of endeavors to generalize these strategies into discrete classes has been carried out. For example, Salehie and Tahvildari [61] identified two categories of self-adaptation based on impact and cost factors. Qureshi *et al.* [62] categorized four different categories of self-adaptive systems: Type 1 consists of systems that anticipate both changes and possible reactions at the design stage; Type 2 consists of systems that own many alternative strategies for reacting to changes; Type 3 consists of systems aware of its objectives and operating with uncertain knowledge about the environment and; Type 4 is inspired by biological systems that are able to self-modify their specifications when no other possible refinements are possible. Analogously, the paper [63] represents four similar types (like [62]) of self-adaptive systems using a metamodel. For IDPT systems, we categorize four different types of adaptive strategies: a) rule-based adaptation, b) adaptation through feedback loops, c) goal-driven adaptation and d) adaptation through predictive algorithms.

### A. RULE-BASED ADAPTATION

As depicted in Figure 4, the rule-based adapting systems, changes its behavior based on pre-defined rules. The psychiatrists manage these rules based on their domain expertise. These rules are in the form `IF <condition> THEN <action>`. We can use the Horn clause [64] to formulate one or more pairs of the conditions. In an adaptive IDPT system, the logical structure of the clauses are of the form:

$$< C_1 \wedge C_2 \vee C_3 \vee \ldots \vee \neg C_n > \implies A_1 \quad (1)$$

$$< C_{k1} \vee \neg C_{k2} \wedge C_{k3} \vee \ldots \vee C_{kn} > \implies A_2 \quad (2)$$

where:
$C_i$ = conditions
$A_i$ = action if the condition is true

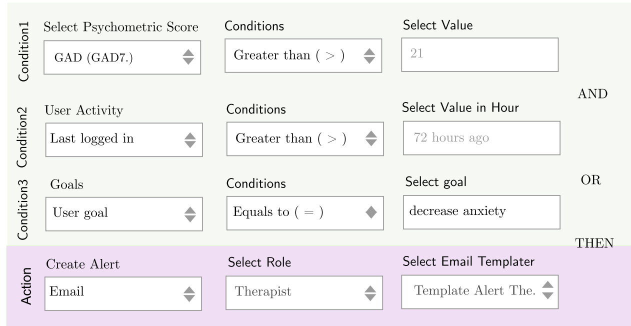


**FIGURE 5.** An example illustrating *rule based adaptation* where a therapist could create several alerts based on *psychometric tests score, user activity, goals and other* appropriate variables.

The quality of these rules and the quality of the performed adaptive actions are measured using several techniques [65] in the literature, including confidence value, rule weight, priority, check function [66], similarity degree, average fitness, case-based reasoning, system metrics and users' preferences [67]. Rule-based adaptation has advantages of readability, transparency, elegance, and they are easily modifiable [65]. According to the same survey, rule-based adaptation has been widely practiced in user interface adaptation [68], process adaptation [66], [69], workflow adaptation, content adaptation [70], software configuration adaptation, and feature adaptation [67]. We show an example of the rule-based adaptation in Figure 5, where an adaptive system sends a reminder (based on predefined email template) to a therapist if the following conditions are `True`:

1) ($C_1$) If the Psychometric score is GAD-7 for Generalized Anxiety Disorder and its value is greater 21 and,
2) ($C_2$) The user has not logged in to the system for more than 72 hours ($C_{2.1}$), or the user's goal is to decrease anxiety ($C_{2.2}$). The condition $C_2$ evaluates to `false` only if both $C_{2.1}$ and $C_{2.2}$ are `false`.

### B. ADAPTATION THROUGH FEEDBACK LOOPS

Feedback loops are regarded as important aspects of self-adapting software systems. Brun *et al.* [71] argue feedback loops as essential for building self-adaptive software systems and for software evolution. A generic feedback loop contains four steps: collection, analysis, decision point, and action [72]. Several sensors based systems are utilized to collect data about the adaptive system's current state and context. The accumulated data are then transformed (cleaned, filtered, pruned, stored) for future referenced. The decision step then analyzes the data to infer trends and identify key patterns. Finally, based on the analysis results, a set of actions are decided that are executed using context actuators.

### C. GOAL-DRIVEN ADAPTATION

In the goal-driven adaptation, the organizational and patient needs, in addition to their goals, are the main factors of adaptation. Heaven *et al.* [73] describes three-layer model controlling goal-driven adaptations- *goal management, change management and control*. The goal management layer

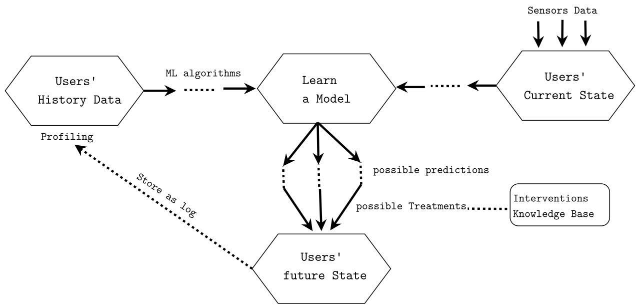


**FIGURE 6. Adaptation based on predictive algorithms: Users' history data is fed to a suitable Machine Learning classifiers, and a model is trained. The users' current state (sensors data) is used as test data with the trained model to get possible predictions. Based on the prediction, a suitable treatment module can be used based on the pre-designed knowledge base.**

handles the creation of a new set of goals or re-planning an existing set. The change management layer controls the adaptation among several tasks at hand based on the goals. Finally, the control layer is the level of execution of the selected configuration.

### D. ADAPTATION THROUGH PREDICTIVE ALGORITHMS

The recent rapid growth in Artificial Intelligence (AI) has opened up unprecedented possibilities in analyzing and predicting diverse phenomena, including humanities, social and cognitive sciences, finances, healthcare, robotics, and other areas of natural sciences. Machine Learning (ML), a subset of Artificial Intelligence (AI), provides principled methodologies for the development of automatic, complex, objective algorithmic models for the analysis of multi-dimensional and multi-modal biological data. For instance, speech data that can be used in automated detection of mental health morbidities with the application of ML approaches. A study was done by Garcia-Ceja *et al.* [59] outlines several studies done about mental health monitoring system that uses sensors and machine learning. Similarly, ML-based algorithms have been used to predict user adherence to IDPT for depression and anxiety after myocardial infarction [74]. The use of ML-based predictive algorithms can be used to increase adaptation in IDPT systems, and the overall process is illustrated in Figure 6.

As depicted in Figure 1, the predictive algorithms are a type of adaptive strategy. These algorithms generally learn complex rules from the users' historical data. We store the patients' history data and feed these data to the predictive algorithms to obtain a trained model. Once we get a trained model, we input any user's current (sensor data) state to the trained model, which provides a set of possible predictions. Based on these predictions, we can get possible treatments based on the intervention knowledge base (KB). Here, we assume based on the domain expert knowledge (therapists), we can design a knowledge base. For example, Generalised Social Anxiety (GAD-7) [47] distinguishes three classes of anxiety based on symptom severity - mild, moderate, and severe. So, a typical KB would contain three different types of interventions for each category. When a user takes this intervention, we store their activities as a log file. We analyze this log file to create an understandable user profile. We refer to this process as user profiling.

## VIII. DEVELOPING ADAPTIVE IDPT SYSTEM BASED ON PBA

In the previous sections, we have outlined several components of adaptive IDPT and covered several aspects of developing adaptive IDPT systems. In this Section, we provide an account of how to design and develop an adaptive IDPT system building on the PBA approach. PBA is well suited to complement the systems architecture and development approach because of it's focus on user needs. Hence, we map the development of an adaptive IDPT system to the PBA approach and present guidelines on how to develop an adaptive IDPT system based on user perspectives and needs. Here we utilize the design scaffolds available in PBA to provide insights into how to build user-friendly and relevant adaptive IDPT systems. The PBA proposes the development of digital health interventions in four distinct stages as depicted in Figure 7; (1) planning, (2) design, (3) development and evaluation of acceptability and feasibility, and (4) implementation and trialing [4]. PBA is a methodology for developing health and illness management interventions, inspired by user-centered design, that has the goal of providing as much value as possible to the end-user. Here, we explore how to supplement and expand the person-based approach with guidelines on how to develop an adaptive IDPT system.

### A. PLANNING

During the planning phase, it is essential to define the problem domain, its scope, context, and main challenges of current problem-solving systems or techniques. Having understood the problem domain, we plan a new system and determine its objectives. We then perform CBA (Cost-Benefit-Analysis) of the proposed system, determine its SWOT (Strength, Weakness, Opportunities, and Threats) features, and finally perform feasibility analysis. The feasibility analysis should focus on different perspectives:

1) *Technical feasibility*: It is recommended to consult technical expertise to determine if the development of the proposed IDPT system is technically feasible.
2) *Economical feasibility*: Financial feasibility is an essential parameter to determine the level and complexity of the adaptive IDPT system.
3) *Legal and ethical feasibility*: The proposed system must abide by the legal requirements of the region and concerned stakeholders. It is relevant to know if the system meets within the legal and ethical constraints of the business, organization, and demography.
4) *Operational feasibility*: It is essential to identify if the proposed system solves the problem space that is originally identified.
5) *Behavioral feasibility*: It is important to take user attitude, behavior, or contextual consent towards

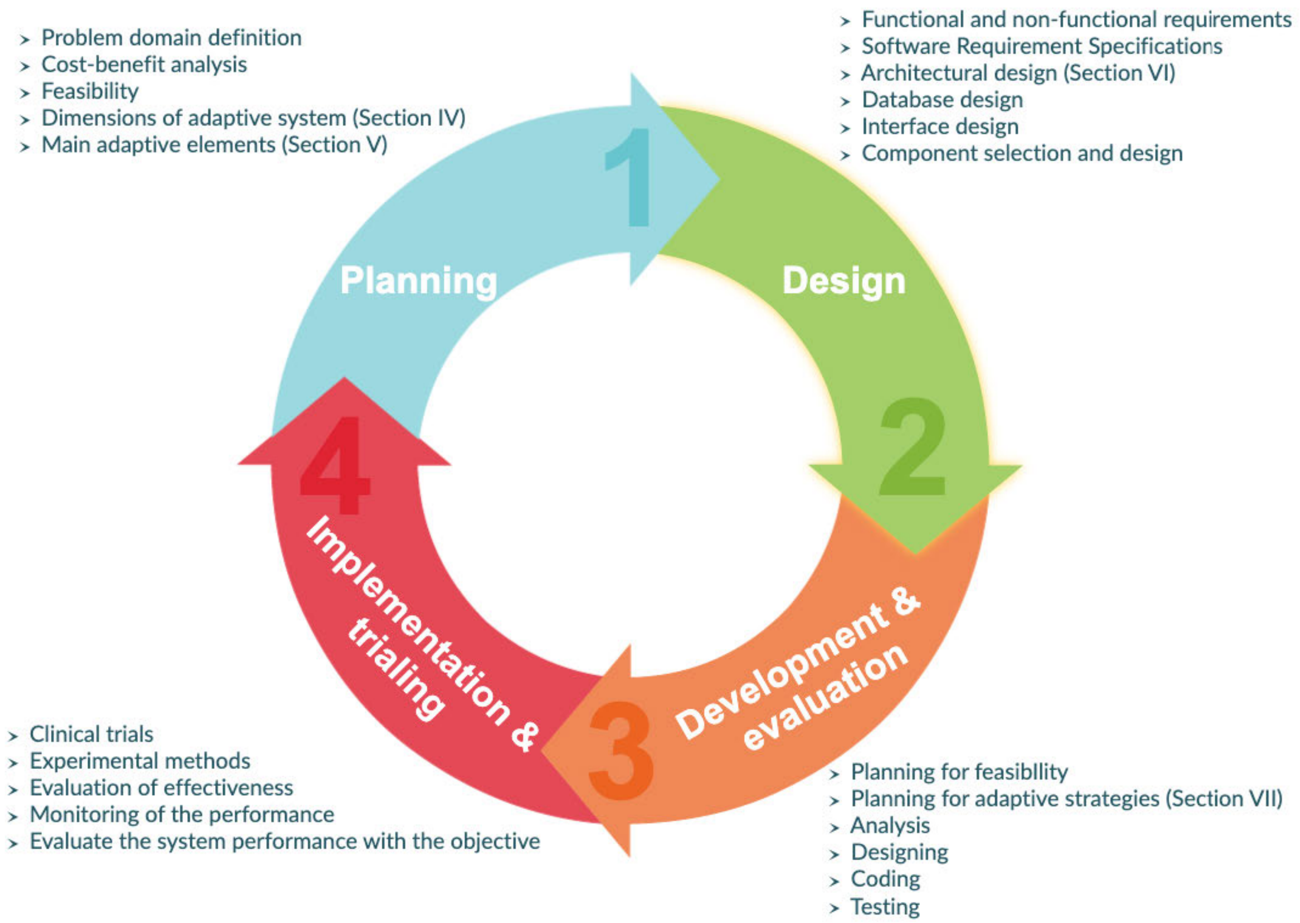


**FIGURE 7.** In this model, we compare the development of an adaptive IDPT system with the Person-Based Approach (PBA) and provide comprehensive guidelines about how to develop an adaptive IDPT system.

the development of the new system. As aforementioned, in Section I, there is currently a sub-optimal patient adherence towards IDPT programs. Hence, it is recommended to take user behavior and their need for the development of adaptive IDPT systems.

6) *Schedule feasibility*: It is essential to know if the adaptive IDPT system can be developed in the allowed time and within the offered resource and budget.

Moreover, we require to work on the design of the user interface and discuss the user interface choices such as multi-touch sensors, gesture-based, Augmented reality (AR) and Virtual Reality (VR) technologies, web-applications, smartwatches, and others. We need to comprehend available technologies and how these technologies assist with adaptation and discuss how users interact with these systems. The problem space needs to be articulated from the perspectives of both computer science and psychotherapy since each has different challenges to develop an adaptive IDPT system. In addition to usability and user experience goals, goals for adaptation are necessary to be considered to define the problem space thoroughly, which results in transferring the knowledge to design space. The main questions that we need to address during planning phases are listed below:

- What is the problem space we are addressing?
- What are the dimensions of the adaptive system?
- What are the main elements we want to adapt?

Theories, previous quantitative research evidence, systematic reviews, meta-analyses can provide insight into the intervention components and perspective of people who will use the intervention. The planning phase of PBA helps in exploring and analyzing the attitudes, understanding, needs, and situations of people who will be interacting with the systems. The exploratory analysis helps to disclose the dimensions of adaptiveness, the choice of user interfaces, and the main adaptive elements required in the intervention. The preference for user interfaces varies according to gender, cultural background, health literacy, or previous experiences. Hence, intervention developers need to consider purposefully sample a diverse range of users who differ in the characteristics to understand their actual needs. Understanding these needs helps to ensure that the researcher has all the insight into all relevant perspectives, allowing to server tailored intervention based on their needs.

### B. DESIGN

During the design phase, we first need to define the requirements, evaluate the possible alternatives, and prioritize these requirements lists. Classifying these requirements into functional and non-functional requirements help to prioritize them.

1) *Functional requirements*: Functional requirements for adaptive IDPT systems include secure authentication and authorization; the ability for therapists to create interventions and adapt based on several adaptive strategies (see Section VII); adaptive dashboard for both therapists and patients; administrative functions; and audit tracking. Moreover, these requirement lists can differ based on legal and organizational aspects.
2) *Non-functional requirements*: Non-functional requirements includes product requirements (usability, dependability, efficiency requirements, interoperability requirements [75]), organizational requirements (development requirements, operational requirements), and external requirements (ethical, regulatory, and legislative requirements) [76].

Based on these requirements list, we need to create a Software Requirement Specification (SRS) [77]. In the design phase, we also need to create a design for the network, databases, user interfaces, and system interfaces. The designers transform the requirements from the SRS documents into the logical structure. These structures include:

1) *Architectural design*: In the architectural design, we identify the overall structure of the system (refer Subsection III-A), the main adaptive elements (refer Section V), their relationships, and their distribution.
2) *Database design*: Database design involves the creation of the system data structures and their relationships.
3) *Interface and interaction design*: Interface design requires the involvement of Interaction Design (IxD) experts to create interactive, precise, and unambiguous user interfaces. Interface design is also concerned with the specification of detail, including syntax and semantics of the services that are provided the user interface. Several structural diagrams can be used to model syntax of the interface, and the semantics of the interface may be defined by using constraint languages for example Object Constraint Language (OCL) [78].
4) *Component selection and design*: In this design, we need to search for reusable components. Since adaptive IDPT is mostly being developed as web or mobile-based apps, there is a large community of open-sourced and proprietary ingredients that helps in building rapid prototyping. Hence, instead of reinventing the well, we recommend identifying the usable components and utilize them for the creation of an IDPT system.

Lastly, we need to review the proposed design and ensure the final design adheres to SRS. The outcome of design phase is detailed *system architecture, database design, interface design,* and *component descriptions.*

### C. DEVELOPMENT AND EVALUATION OF ACCEPTABILITY AND FEASIBILITY

In the development and evaluation phase, the developers transform the design specifications into source code, where several modules come together to perform an integrated system. This phase is also referred to as the *coding* phase and is the most prolonged phase of a development life cycle. It includes careful development planning, plan analysis, designing, actual coding, and testing.

- During the development planning phase, the development needs to decide appropriate programming languages, frameworks, databases, versioning systems, project management tools, and other tools required to develop the adaptive IDPT system. The process of selecting tools requires necessary feasibility analysis concerning business goals, available budgets, and schedules.
- The analysis involves making the detailed logical architecture of the applications, network, and database. An analyst decomposes the system into several parts called "Objects". Decomposition helps to identify reusable components increasing development efficiency and cost-effectiveness.
- The Designing phase is a creative step that involves making decisions about the system, for example which programming language to use, which database vendors to integrate, hardware, and network decisions.
- Coding is a mathematical approach that involves how logic operates. Coders follow specific styles, formats, and patterns to create the programs.
- Finally, the testing phase involves the verification and validation of the product. It consists of debugging by the programmers to ensure that the programs execute as intended. In addition to debugging, the product should need to go through the quality assurance (QA) process. QA involves acceptance testing that allows validating the software based on the original SRS. Acceptance testing involves several other forms of testing, including system testing (load testing, stress testing), integration testing, compatibility testing, user testing, and others [79].

### D. IMPLEMENTATION AND TRIALING

In this stage, we apply the adaptive IDPT system into practical use - that is, clinical trials and experimental evaluations. Evaluation of problem space and user needs, usability, and user experience is an essential aspect of the development of digital tools that should be performed during development. When a stable and usable system is achieved, measuring and building evidence of the medical effects of the intervention is equally important. The development of online interventions requires a combination of the scientific traditions of computer science and medicine. In practice, the traditions have different conceptions of what can be taken as evidence, and how to construct it, and requires the evidencing to take place over different temporal phases. Corrections can be done in a pilot

**TABLE 2. List of related studies attempting to adapt IDPT systems.**

| Reference | Year | Objective | Main findings |
|---|---|---|---|
| Brian *et al.* [57] | 2005 | Reviews the roles of considering IA designs for effective web-based interventions | Encourage adoption of a multidisciplinary perspective IA for presenting content of behavior change interventions. |
| Webb *et al.* [82] | 2010 | Investigate which characteristics of IDPT best promote health behavior change | a) IDPT incorporating more behavior change techniques (stress management, communication skills, problem-solving and others) have larger effects on outcomes. b) Additional communication with participants using SMS, email, messages increases adherence. |
| Christensen *et al.* [83] | 2009 | Review adherence with respect to IDPT and investigate the rates of dropouts and compliance in RCT for anxiety and depression | Main predictors of adherence include disease severity, treatment length, and chronicity. Very few studies examined the actual reasons for dropout. |
| Andersson *et al.* [18] | 2019 | Literature review arguing ICBT can be viewed as a vehicle for innovation | Detailed review in several directions including effectiveness of IDPT, implementation paradigm, predictors and future works. |
| Kelson *et al.* [84] | 2019 | Examine the therapeutic impact of Internet-delivered acceptance and commitment therapy(iACT) on all anxiety conditions. | Results indicate iACT to be efficacious and acceptable treatments. |
| Jokste *et al.* [65] | 2017 | A systematic review of rule-based adaptation to discover types of rules applied, application domains, and performance measures. | a) Results indicate widely adopted in medicine-related system, an adjustable system for people with disabilities and others. b) Categorized three forms of semantic rules: event-condition rules (if-else), association rules, and RuleML based behavior rules. |
| Karyotaki *et al.* [85] | 2006 | Examines the predictors of dropout in an individual patient data meta-analysis | a) Dropout can be predicted by several variables and is not randomly distributed. b) Understanding these variables can help to adapt IDPT to prevent dropout in identified groups at risk. |
| Rogers *et al.* [86] | 2017 | (a) discover the range of health-related topics that are addressed through Internet-delivered interventions, (b) generate a list of current websites used in the trials, and (c) identify gaps in the research that may have hindered dissemination. | Wide range of IDPT is available for health-related behavior. However, most of the IDPT found to be efficacious in RCT does not have a website for general use. |
| Brouwer *et al.* [87] | 2011 | Identify (a) which potentially exposure-promoting methods and strategies are used in existing IDPT, b) which objective measures are used to measure exposure to IDPT, c) which methods are associated with better exposure. | Feedback, interactive elements, and email/phone contact was mostly used methods and strategies to increase treatment outcomes. No clear conclusion is drawn due to the diversity of intervention methods used and inconsistency in reporting. |
| Pugatch *et al.* [50] | 2018 | Synthesize the existing literature on website information architecture and its effect on health outcomes, behavioral outcomes, and website engagement. | The authors only found three relevant papers. The first paper that investigated IA exclusively found that a tunnel IA improved site engagement and behavior knowledge, but it decreased users' perceived efficiency. The second and third papers found that a tailored site condition improved site usage, behavior knowledge, and some behavior outcomes. |

trial where the developed adaptive IDPT system is accessed by users who test if an intervention is technically working, the presence of logical errors, and other functionalities by initial requirement specifications. The testing of adaptability in a clinical trial requires an evaluation of all potential configurations of adaptive components. To measure the medical outcomes and effects of adaptability requires a comparison of adaptive systems to non-adaptive systems. Additionally, adaptive aspects or elements of a system can be compared to non-adaptiveness or each other. Currently, Randomized Controlled Trials (RCTs) are not well matched to the pace of technology development, and there is a need for methodologies that can account for effects more rapidly [80]. One recent methodological approach that is aimed at meeting evidence demands from medicine, simultaneously to being relevant to methodological requirements from technology development is found in micro-randomized trials [81] Micro-RCTs aims to provide a data-based method for evaluating online interventions by providing an experimental design for use in testing the proximal effects of the newly developed treatments.

## IX. RELATED WORKS

With the prevalence of mental health illness, on the one hand, the enhancement in ubiquitous computing on the other, several authors have attempted to adapt intervention in several ways with different objectives. Table 2 contains a list of similar studies done previously. The studies [50], [57] reviewed the roles of IA designs for effective web-based intervention. However, the studies are limited to IA and behavior changes. In particular, IA is just one of the characteristics of IDPT. Webb *et al.* [82] performed a systematic review to investigate which characteristics of IDPT best-promoted health behavior and reported IDPT that incorporated more behavior change techniques (stress management, communication skills, problem-solving and others) have more significant outcomes. However, it is still not sufficient to build an adaptive system only based on behavior change techniques, as several other dimensions (disease diversity, treatment length, chronicity) contribute to user adherence in the IDPT system [83].

Christensen *et al.* [83] performed a systematic review to investigate adherence to IDPT and the rates of dropouts for anxiety and depression. The study reports the main predictors of adherence are disease severity, treatment length, and chronicity. However, the study by Karyotaki *et al.* [85] reported that several variables could predict dropouts, and these variables are not randomly distributed. Understanding these variables can help to adapt IDPT and prevent dropouts in the identified groups as a risk. Adhering to this conclusion, we aim to present, in our study, several variables (adaptive dimensions) that affect adaptation.

Jokste and Grabis [65] conducted a systematic review of rule-based adaptation to discover types of rules, application domain, and performance measurement. The study by Brouwer *et al.* [87] attempts to identify which exposure-promoting methods and strategies are used in existing IDPT system and identify performance measures in the IDPT environment. The study reported that feedback, interactive elements, and email/phone contact were mostly used strategies. However, no clear conclusion was drawn due to the diversity of intervention methods used and inconsistency in reporting. While the study uses feedback, interactive elements, and email/phone contact as strategies, these are just the rule-based adaptation mechanism. Feedbacks, supports are the adaptive elements.

Rogers *et al.* [86] attempted to discover the range of health-related topics that are addressed through Internet-Delivered interventions and identify the gaps in the research that may have hindered dissemination. The study reported a wide range of IDPT systems is available for health-related intervention. However, most of the IDPT reported being efficacious in RCT trials does not have a website for general use. Hence, the internal architecture, adaptive elements, and strategies used remain unknown for the research community. Andersson *et al.* [18] performed a systematic review arguing ICBT can be viewed as a vehicle for innovation and reported several directions, including the effectiveness of IDPT, implementation paradigm, and future works.

However, none of the studies reported a reference model of an adaptive IDPT system with its major components nor provided comprehensive guidelines on developing an adaptive IDPT system.

## X. CONCLUSION

In this paper, we propose a model for adaptive IDPT based on classical control theory and discuss how the model can be used to represent an adaptive IDPT system. In addition to the model, we outline the core components of adaptive IDPT systems, the main adaptive elements, dimensions of adaptiveness, information architecture applied to adaptive systems and strategies used in the adaptation process. We also provide comprehensive guidelines on how to develop an adaptive IDPT system building on the Person-Based Approach. Patient adoption of and persistence with the IDPT intervention program is a prerequisite to successful outcomes of the therapy, which requires the combination of the perspectives of computer science and psychology/behaviour science when building the intervention. Here, we have proposed to combine a user-centered design approach with systems that adapt to patient behavior. Adaptive IDPT systems have the potential to offer personalized treatment to the far-reaching population with lesser use of resources, ensuring higher user adherence, reduced dropouts, and better treatment outcomes, and equally important: to achieve successful therapeutic outcomes for those affected.

In the future, we need tools, frameworks, architecture for an adaptive IDPT, and Domain-Specific Languages (DSL) for adaptive IDPT to facilitate the development of scalable, interoperable, and secure adaptive IDPT systems. We also need better dashboard tools that help therapists and other medical practitioners to comprehend the patients status better and adapt their interventions based on their engagement with the interventions. Thoroughly testing the adaptive IDPT system model and all the types of adaptive strategies have been kept as one of our project's immediate work.

## ACKNOWLEDGMENT

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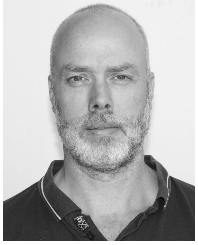

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