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Leveraging Axiomatic Design and Research Information Systems to Promote Research Outcomes at Public Universities

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ABSTRACT Due to the ever-stringent regulatory standards and financial pressure imposed by governments worldwide, public universities are striving to produce and deliver high quality knowledge by leveraging various organizational and technological tools. Despite their prominence and proliferation, research information management systems (RIMS) cover only the research management life-cycle of the institution and thereby presume that the scholars are actively engaged in research and are committed to feeding the system with accurate research data, which may not be the case at public universities. In this paper, we propose to leverage Axiomatic Design and Research Information Systems to support the entire research production life-cycle. The architecture of the proposed system is described in terms of a set of software modules, which may be incorporated into an open-source or a commercial Current Research Information System (CRIS). This will extend the CRIS functionality to cover the research production life-cycle in addition to the research management life-cycle making it well suited for developing research capacity at public universities.

INDEX TERMS Axiomatic design, current research information systems, research support systems, research capacity.

I. INTRODUCTION

Public universities worldwide are funded partly or totally by governments, and as such they focus mainly on producing and delivering high quality knowledge in diverse disciplines. Owing to the significant decline of public funding on one hand [1], [2], and the outcome-based education paradigm shift, requiring higher education institutions to promote the research activity in order to qualify for academic accreditation on the other hand [3], [4], public universities are shifting towards promoting research activities qualitatively and quantitatively [5]. Boosting research outcomes at public universities, not only provides an extra source of income through external funding, to compensate the decrease of public funding, but also helps to achieve institution and program accreditations [4].

Despite numerous efforts to institutionalize research at public universities, through the development of research strategic plans [6], [8], research productivity in the public sector is far from being satisfactory [7], and many public universities are still striving very hard to strike the balance between quality teaching and increasing their research capacity. This is partly due to the inherent financial and legal constraints imposed on public universities [1]. Moreover, the latter constraints hamper the implementation of some action plans, which for example, recommend the recruitment of new highly qualified scholars [2]. In addition to that, public higher education institutions face difficulties pertaining to the adoption of effective policies, which are in turn capable of incenting and steering existing faculty members towards more productivity in both research and teaching, either indirectly through internal incentives, or directly through monitoring and support [9]–[11].

Research strategic plans [12], [13] are formulated by strategic planning committees and communicated by formal research managerial structures at the public institution, such as vice presidency of research, deanship of research and various research centers and directorates. Despite their popularity and adoption by most public higher education institutions as a means to achieve the institution's research mission, their

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implementation is often challenging [14], [15], and requires some changes in the structure of the organization [16]. Furthermore, implementing research strategies relies heavily on the development of institutional policies, which in turn, rely on the experience, skills and ingenuity of the institution managers to find appropriate instruments for achieving the objectives assigned to them. Moreover, due to the lack of control over the allocation and utilization of resources, the development of a strategic plan for research in academic institutions is totally different and much more challenging than the usual strategic plans for the institution [17].

Recent developments in the field of design theory such as Axiomatic Design [18], C-K theory [19], and others [20], which were initiated during the past few decades in non-managerial fields of study namely, mechanical engineering and information systems have gained prominence and wide acceptance, not only in their own native fields of development, but also have been successfully extended to deal with virtually any product or process [18]. Design theories aim at developing scientifically based methodologies for the design of high-quality products and processes. Strengthening knowledge production at public universities, which is the central focus of the present paper, can be viewed as a process and thereby should benefit from these developments. Indeed, the well-developed Axiomatic Design methodology, (AD) for example, stresses in its first axiom that the institution's research strategic objectives should be as independent as possible for a design to be qualified as a ''good'' design. In essence, the independence axiom provides the necessary guidance to disentangle as much as possible the functional requirements (FRs) by successive decompositions until appropriate design parameters (strategies) are found to satisfy the independence axiom.

Furthermore, advances in Information Systems (IS) dealing with the management of the research life-cycle, such as Institutional Repositories (IR) and more recently Current Research information Systems (CRIS) [21], [22] offer effective instruments for disseminating and managing the research activity. These tools not only aid in accurately measuring the various key performance indicators, but also support scholars in various research tasks, such as making quick submissions to research grants, both nationally and internationally. However, these systems lack support of the research production life-cycle from the choice of the publication title to the acceptance of the research paper. It is the purpose of the present paper to leverage both axiomatic design methodology and research information systems for the development of an effective system, which is capable of strengthening knowledge production at public universities. Towards this goal, the next section will cover related work on developing and strengthening research capacity, followed by a brief introduction to the concepts and tools of Axiomatic Design. Section four is devoted to our main contribution geared toward the development of an axiomatically designed research information system along with implementation guidelines of the proposed system, followed by a discussion and future work. References are given in the last section. In what follows, we attempt to review briefly the related work on developing research capacity in an effort to make the paper as self-contained as possible, accessible to a large audience and demonstrate and contrast the strengths of the proposed approach, compared to the state of practice. Nonetheless, readers familiar with RIMS/CRIS, research strategic planning, axiomatic design and research support systems may jump to the results Section IV without any loss of information.[1]

II. RELATED WORK ON DEVELOPING AND STRENGTHENING RESEARCH CAPACITY AT PUBLIC INSTITUTIONS

In this section, we briefly overview the current approaches and practices aimed at developing and strengthening research capacity at public universities namely, research information systems (RIS/CRIS), research strategic planning and research support systems.

A. RESEARCH INFORMATION SYSTEMS (RIS/CRIS)

With the advent of web technologies, archiving research outcomes have evolved in the course of time to take various electronic forms namely, institution repositories (IR) [23], which are commonly hosted on the institution's portal. IR's are specific to the institution and are openly accessed through a web interface by the institution's scholars, for both submission and review, and also by anonymous scholars for download and comments. Software applications supporting the creation and management of IR's are readily available for use under the open source license agreement [24] and therefore any institution can build and run its own repository with minimum cost. Furthermore, aggregator websites [25] allow efficient access to all registered IR's. A key advantage of IR's is to enhance visibility of the university research achievements and thus contribute to the institution's webometric ranking [26]. Despite their proliferation, IR's face numerous challenges [27], [28], and to the best of the knowledge of the authors, their effect on boosting research production has not been reported yet.

Motivated by the dissemination of knowledge worldwide, research information management systems (RIMS) [29] and more recently current research information systems (CRIS) initiatives [30] were launched during the past few decades, and many institutions worldwide have already started using them effectively. The main functions of Current Research Information Systems (CRIS) are to store, manage, and exchange data pertaining to research activities, including researchers and research groups, their projects, funding, etc. for the purpose of documentation, communication, and administration [31], [32]. They produce valuable information for the preparation of applications for funding, project reports, researcher profiles, CV's, to name a few.

[1] Suggested by an anonymous reviewer.

RIMS harvest data from various sources and can interface with both IR's and other RMIS [33]. They reflect the research achievement profiles of both the individual researchers as well as the institutions as their basic core functionality. They also perform numerous management tasks, such as award and opportunities management, publications management, scholar profile management, research reporting, compliance with internal/external mandates management, and support of open access IR's [33]. They may also have some other specific functions, depending on the particular implementation, such as building various reports and carrying out performance assessments and managing the entire grant process research lifecycle.

As the main focus of RIMS/CRIS is to manage the research life-cycle rather than the research building and strengthening capacity life-cycle, they suffer from low researcher participation [34]. Numerous research works have studied the issue of user involvement in RIMS/CRIS since the early days of their inception [35], [36], [37]. Despite their prominence and adoption by many universities, none of the RIMS/CRIS cited in [25] provide a clear and proven strategy for the active involvement of the researchers particularly, at public universities. Moreover, RIMS do not manage the research production process of scholarly work, especially when it is too early to decide on its dissemination.

B. RESEARCH STRATEGIC PLANNING

Strategic planning is defined as "formalized procedures in the form of an integrated system of decisions that produce articulated results" [38]. Strategic planning of research at a public institution starts from the vision and mission statements of the research activity at the public institution, followed by an analysis of strengths and weaknesses, opportunities and threats (SWOT) to categorize the institution's significant environmental factors, both internal and external. Some authors consider the latter being the most commonly used as well as the highest ranked tools for planning strategies [39]. Despite its popularity and ability to identify not only the internal strengths and weaknesses of an organization, but also the external ones, SWOT as a tool has several shortcomings, such as the accurate classification of the factors being strengths, weaknesses, opportunities or threats. Indeed, if the strengths are not well maintained, they may turn into weaknesses, and if opportunities are not taken and adopted by competitors, they may turn into threats. Moreover, SWOT is over-simplified, not agile enough to complex market changes and does not provide sufficient context for adequate strategy optimization [40], [41], [42]. More importantly, and notwithstanding its popularity, SWOT analysis does not provide any guidance for formulating the strategic goals into more concrete sub-goals that can be turned into single projects, which helps to improve the organizations' efficiency.

C. RESEARCH SUPPORT SYSTEMS

The information system (IS) literature offers very few pointers pertaining to research support systems, because of a lack specific methods and guidelines for their development [43], [44]. Nonetheless, some attempts were made in this direction of research, where a mobile RSS was developed under the name of "iScholar" [44]. The main functions of the latter system are the retrieval of relevant papers and the recommendation of related papers and it is comprised of four software components namely, Search, Recommendation, Article Management and Personal Information. It is noteworthy that the latter system lacks support for research collaboration. Moreover, the recommendation component is part of the system, which was developed in an ad-hoc manner rather than relying on state-of-the-art methods in the emerging field of information retrieval. In [45], the authors proposed along the same direction, another RSS system to support research activities, named CUPTRSS, which is comprised of four modules namely, Research Management, Resource Management Expertise, Collaborative Support and Information Support. Despite its support for research collaboration and the numerous useful tools for researchers such as an ad-hoc search engine using information retrieval techniques, the authors of CUPTRSS did not give much implementation details of their system. Furthermore, no account has been made for motivating scholars to use the system effectively, and thereby mitigate the risk of its rejection. More recently, additional attempts to develop research support systems were made in [46], where the authors proposed an adaptive system to support students to acquire research skills. Despite its adaptivity to the student context, the latter system requires a research mentor to provide comments and guidance to research students. Moreover, no details were given by the authors on how to perform the various research tasks by the system. In [47], the authors elaborated a research support system named (RAC) to aid newly assigned students to a laboratory with their research using gamification in order to keep the user's motivation high. RAC incorporates both Papits [48] for paper recommendation and MIRASS [49] for medical papers retrieval. Despite the encouraging and limited empirical results obtained with RAC, the latter remains very limited to specific laboratory disciplines and its extension to other disciplines reveals extremely laborious. Moreover, no attempt was made by the authors to extend RAC to encompass research activities of the faculty of the institution. An attempt was made by the authors of RAC to incorporate automatic extraction of task statements during discussions in seminars into the RAC system.

III. METHODS AND MATERIALS

A. AXIOMATIC DESIGN THEORY

Axiomatic Design Theory [18] aims at achieving "optimal" designs, of both products and processes, by following an end-to-end, mathematically motivated and structured approach. According to AD theory, a design of a product or a

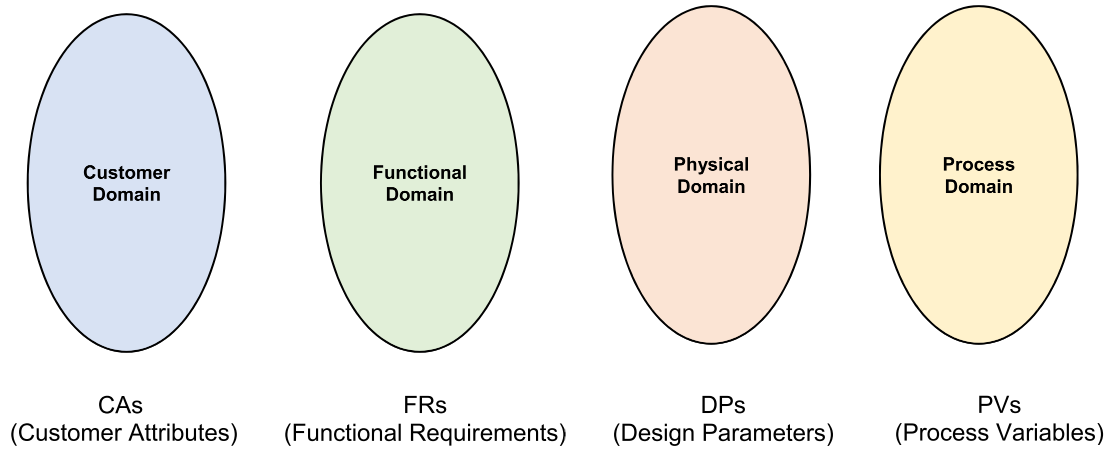

FIGURE 1. The four domains of axiomatic design.

process reflects the mathematical relationship between the design parameters DPs (strategies), and the product/process characteristics, also called functional requirements FR's. Whereas in engineering applications such as mechanical design [50], the DP's can be the length of a rod, stiffness of a spring etc., and the functional requirements are the braking distance, caliper adjustment, in business applications, such as strategic planning, the functional requirements are the strategic objectives or goals, expressed in the mission statements, and the design parameters are the strategies [51] A "good" design, in the sense of AD theory, is the one that satisfies the two following conditions, also called axioms [18]:

1) The independence axiom, which requires a design, to have independent functional requirements (FR's). The motivation behind is to prefer designs with disentangled functional requirements,
2) The information axiom is about designing products/processes which are insensitive to variations in the DP's.

Guided by the independence and information axioms in the search process of a good design, AD theory departs considerably from other design practices, such as quality engineering [52]. It is worthwhile to mention here that whereas quality engineering focuses on a single quality characteristic, and thereby ignores the relationships between multiple quality characteristics of the design, AD typically considers multiple functional requirements as well as their relationships to the design parameters, which are expressed in terms of the structure of the design matrix [18]. In what follows, the main concepts of AD, namely Design Domains, Zigzagging and Design matrix will be briefly reviewed.

B. DESIGN DOMAINS

Axiomatic Design considers four design domains namely, Customer Attributes (CAs), Functional Requirements (FRs), Design Parameters (DPs) and Process Variables (PVs) shown in Figure 1.

The designer starts with a set of attributes, called customer attributes (CA's) in the Customer Domain, which characterize the product or the process from the stakeholder point of view. In the case of public institutions, the stakeholder is the state who owns the institution. Notwithstanding the nature and diversity of organizations, the customer attributes, also known as customer needs, are always stated explicitly in the vision/mission statement (and the constraints are expressed in the mission statement). Given the CA's of the desired product or process, the designer seeks a set of functional requirements, denoted by FRs, in the Functional Domain, to achieve the latter customer attributes whilst satisfying some physical constraints. Whereas the Customer Domain answers the question "what to achieve" in terms of CA's, the Functional Domain answers the question: "How to achieve the customer attributes" in terms of Functional requirements. In the case of strategic planning, the CA's are expressed in the vision statement and the FR's are the strategic goals, which are expressed in the mission statement [12]. Once a set of FR's, satisfying the independence axiom (to some extent), have been found, the designer proceeds next to the Physical Domain to determine for each FR a physical embodiment, called Design Parameter (DP), which answers again the question "How to physically achieve a given FR". In the case of strategic planning, DP's are exactly the strategies, designed to achieve the strategic goals. More specifically, in the case of software design, the DP's are the inputs to the software modules, which correspond to the FR's [18].

C. ZIGZAGGING

AD adopts a unified search methodology (algorithm) for making the transition back and forth between the Functional and Physical Domains, which is known as Zigzagging in the AD literature. Starting from the top-level FR and selecting the

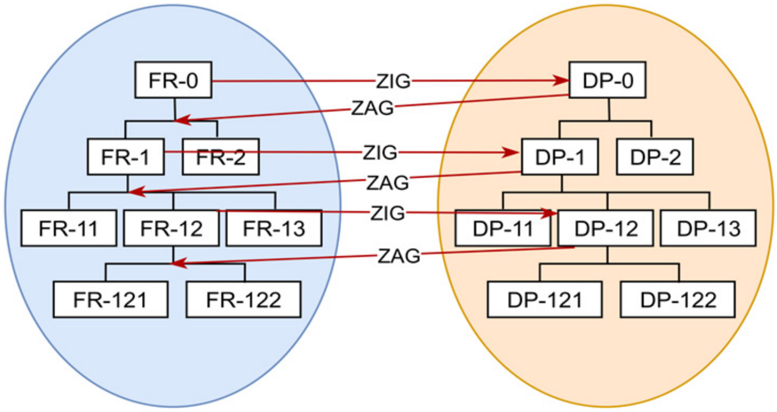

FIGURE 2. Zigzagging.

corresponding top DP, which is generally not obvious how to implement physically, the designer proceeds by decomposing the parent FR into two or more sub-FRs, which must be mutually exclusive and collectively exhaustive (MECE) [53]. The children FRs, obtained this way, will be associated with their corresponding DPs. This process of simultaneously decomposing an FR and determining the corresponding DP is called Zigzagging [18]. More precisely, zigging is taking place from FRs to its corresponding DPs, and zagging from the DP to the FR. Fig. 2 depicts the Zigzagging concept. It is worth noting that Zigzagging is probably the most difficult process in AD practice, as it requires domain knowledge, and thereby constitutes an impediment for the application of Axiomatic Design to various design problems.

D. DESIGN MATRIX

In AD, the design matrix (DM) mediates the relationship between the DP's (strategies) and the FR's (strategic objectives) in the following FR-DP (G-S) equation:

$$FR = [DM] * DP \tag{1}$$

equivalently,

$$G = [DM] * S \tag{2}$$

which can be expressed in vector notation for a generic parent strategic goal G with three sub-goals $G1$, $G2$ and $G3$ as:

$$\begin{bmatrix} G1 \\ G2 \\ G3 \end{bmatrix} = \begin{bmatrix} X & & \\ X & X & \\ X & X & X \end{bmatrix} \begin{bmatrix} S1 \\ S2 \\ S3 \end{bmatrix}$$

where the design matrix in this case is

$$\text{DM}= \begin{bmatrix} X & & \\ X & X & \\ X & X & X \end{bmatrix}.$$

The i^{th} row of the design matrix [DM] expresses the sensitivities of the corresponding i^{th} functional requirement FR_i to the various design parameters DP_j [50]. A zero entry in the i^{th} row and a the j^{th} column of the matrix [DM] means that FR_i is not sensitive to the inherent variations in the j^{th} design parameter DP_j. The design matrix is not meant to express the functional relationships of the multivalued response function [FR], but it rather represents its Jacobian matrix, and that's why at a first glance from looking at the algebra in the equation (1), which relates the DP's to the FR's, it seems that AD is dealing only with linear response functions. This confusion stems essentially from the misunderstanding of the non-zero entries expressed by the symbol 'X' in the design matrix, which are not meant to be necessarily constant terms, but rather response functions.

E. APPLICATION OF AXIOMATIC DESIGN IN STRATEGIC PLANNING

Since its early inception, AD has found widespread applications in many industrial domains and to a lesser extent in the strategic management practice [54]. More specifically, the authors are not aware of any research work about using AD and Information Systems to develop and strengthen research at public universities. Yet, there were a few attempts to use AD in strategic planning: in [51], AD was extended to plan a company's specific strategy. More recently, AD was used to analyze the design of an organization [55], where the author argued that neither organizational theory, which is of descriptive nature, nor strategy theory, which assumes that organization design is a matter of selecting a pre-existing organizational form that fits certain external or internal contingencies, is suitable for the above-mentioned task and proposed instead a hybrid approach involving both systems design and AD theories.

IV. RESULTS: AN AXIOMATICALLY DESIGNED RESEARCH SUPPORT SYSTEM FOR DEVELOPING AND STRENGTHENING RESEARCH CAPACITY AT PUBLIC INSTITUTIONS

This section discusses the elaboration of a research support system, thereafter called ADRESS, for developing and strengthening research at public universities using Axiomatic Design methodology. In order to delimit the scope of the implementation of our proposed system, it is assumed that the public institution under consideration is already engaged in a program aiming at achieving quality teaching, and therefore the latter objective may be considered as a constraint, rather than a strategic goal. Toward this end, the proposed design starts with specifying our root strategic goal, which can be stated as follows (Fig. 3):

G0: "Develop and strengthen research capacity whilst sustaining quality teaching"

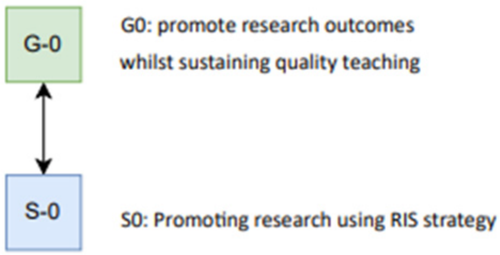

FIGURE 3. Level-0 decomposition: the double arrows illustrate zigzagging.

In order to achieve the above strategic root goal G0, several detailed strategies have been proposed for Higher Education Institutions [8], [12], [16]. It is noteworthy that most of these strategies are not applicable in the context of typical public institutions, as they involve for e.g., the recruitment of external distinguished active researchers, which in turns requires considerable investments. Notwithstanding the latter issue, the formulation of effective strategies for developing and strengthening research capacity requires a different approach than the other strategic planning tasks at Higher Education Institutions (HEI), due to the lack of tight control over the allocation and utilization of resources for research, which requires a high level of individual commitment and focus [17]. Moreover, the details of the implementation of the above-mentioned strategies are not always clear, and their success relies on the ingenuity and skills of the managers, who must develop appropriate action plans along with key performance indicators to achieve these strategies. In the context of public institutions, our main strategy for achieving the goal G0 relies on the effective use of a specifically designed research support systems (RSS), and can be stated as follows:

S0: "Develop and strengthen research capacity by the effective use of RSS" strategy

Since it is not clear yet how to implement the above-mentioned strategy S0 in the context of public universities, the strategic goal G0 needs to be further decomposed into one or more sub-goals along with their corresponding sub-strategies. In doing so, we must keep in mind the application of the independence axiom, by maintaining the strategic sub-goals as independent as possible [18]. In other words, the strategies must be chosen so that the final design is decoupled. It is worth noting that this "stopping criterion" is what distinguishes AD from classical strategic planning practice, in the sense that at each step the designer must make sure that for each strategic goal (FR), the corresponding strategies (DP's), can be effectively embodied.

A. LEVEL-1 DECOMPOSITION

At this level, our main goal G0 will be decomposed into a set of sub-goals, such that equation (1) must hold. Since our main strategy relies on the effective use of a well-designed research support system (RSS), G0 can be achieved by setting the following strategic sub-goals (Fig. 4):

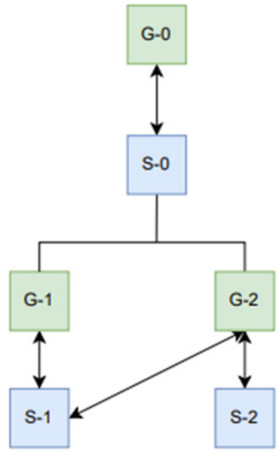

FIGURE 4. Level-1 decomposition: the double arrows illustrate zigzagging.

G1: "Design the RSS as to develop and strengthen research at the institution"

G2: "Get the faculty members to be active and productive users of the RSS system"

The corresponding strategies at this level are:

S1: "Institution's RSS development" strategy

S2: "Effective use of RSS" strategy

The relationship linking S1, S2 to G1, G2 can be expressed as:

$$\begin{bmatrix} G1 \\ G2 \end{bmatrix} = \begin{bmatrix} X & \\ X & X \end{bmatrix} \begin{bmatrix} S1 \\ S2 \end{bmatrix} \quad (3)$$

Equation (3) indicates that in order to achieve the goal (G1) i.e., design the RSS as to develop and strengthen research capacity, we need to deploy strategy (S1) alone, i.e., develop the institution's RSS independently of its effective use. However, in order to achieve the strategic goal (G2), i.e., to get the faculty members to be active and productive users of the system, we need to deploy both strategies namely, developing a well-designed RSS system and also making effective use of it. In the design matrix we put an X to indicate that the element is a non-zero value. The first level decomposition of G0 is shown in Fig 4. In this case we are dealing with a decoupled design. Finally, since it is not clear yet how to implement neither the strategy S1 nor S2, both sub-goals G1 and G2 need to be decomposed further and this will be performed in the second level decomposition.

B. LEVEL-2 DECOMPOSITION

Since it is not yet clear how to implement the strategy S1, which consists of designing the RSS as to develop and strengthen research, the goal G1 must be decomposed further into the three-following level-2 sub-goals (Fig. 5):

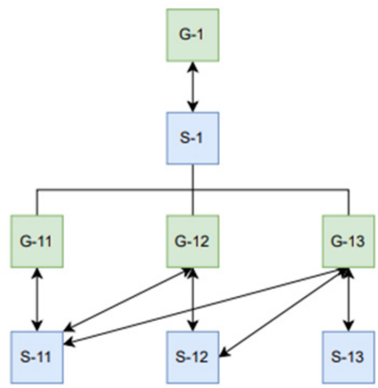

FIGURE 5. Level-2 decomposition of the goal G1 the double arrows illustrate zigzagging.

G11: "Provide streamlined and secured access to the RSS system"

G12: "Facilitate the search for potential research ideas"

G13: "Facilitate the publication process from within the RSS"

The corresponding strategies for the above three level-2 sub-goals can be stated as follows:

S11: "RSS general design and access" strategy

S12: "Potential idea search" strategy

S13: "Streamlined publication process" strategy

The equation FR-DP for this decomposition level can be expressed as:

$$\begin{bmatrix} G11 \\ G12 \\ G13 \end{bmatrix} = \begin{bmatrix} X & & \\ X & X & \\ X & X & X \end{bmatrix} \begin{bmatrix} S11 \\ S12 \\ S13 \end{bmatrix} \quad (4)$$

As shown by equation (4), the sub-goal G11, which pertains to the design aspect of the RSS can be achieved through the application of S11 alone, and this regardless of the other remaining strategies. However, the sub-goal G12, which pertains to the facilitation of the search for potential ideas needs both the application of the strategies S11 and S12. Finally, the sub-goal G13 pertaining to the facilitation of the publication process from within the RSS system needs all the three strategies namely, S11, S12 and S13. Since the design matrix in equation (4) is a lower triangular, it follows that the design is again a decoupled design. Likewise, since it is not clear how to implement the strategy S2 i.e. how to get the scholars to use the RSS effectively and be productive, it follows that the goal G2 must be decomposed further. Toward this end, a marketing and motivation strategy must be put forward, which requires introductory training sessions, various workshops on how to select a potential research idea and how to choose a title and finally, write an acceptable abstract. Therefore, the sub-goal G2 must be decomposed into the following four sub-goals (Fig. 6):

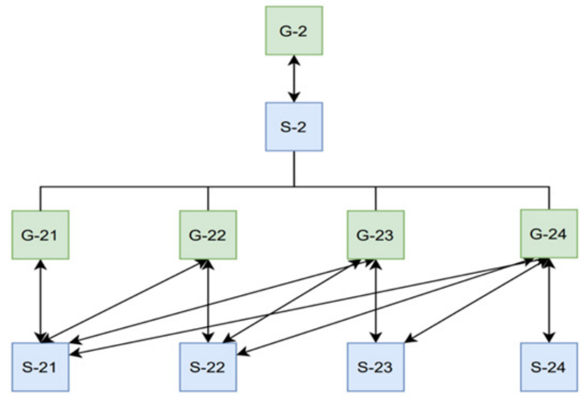

FIGURE 6. Level-2 decomposition of the goal G2: the double arrows illustrate zigzagging.

G21: "Get the faculty members to attend the RSS tutorial presentations and training sessions",

G22: "Get the faculty members to learn how to register to the RSS and interact with the system during tutorial sessions",

G23: "Get the registered faculty members to learn how to select a potential research idea using the RSS system",

G24: "Get the registered faculty members to learn how to submit an accepted abstract to the system".

The corresponding strategies for the abovementioned goals can be formulated as follows:

S21: "RSS marketing and motivation" strategy

S22: "RSS introductory training" strategy

S23: "RSS specialized workshops on choosing a potential research idea" strategy

S24: "RSS training on how to choose the title, write an acceptable abstract, an introduction and the paper road map" strategy

The equation relating the strategies to the strategic goals can be expressed as:

$$\begin{bmatrix} G21 \\ G22 \\ G23 \\ G24 \end{bmatrix} = \begin{bmatrix} X & & & \\ X & X & & \\ X & X & X & \\ X & X & X & X \end{bmatrix} \begin{bmatrix} S21 \\ S22 \\ S23 \\ S24 \end{bmatrix} \quad (5)$$

Equation (5) shows that in order to get the faculty members to attend the RSS tutorial sessions, we only need to apply the strategy S21 i.e., we need to deploy the marketing strategy independently of the remaining three strategies, and as was mentioned earlier, the deployment of the marketing strategy will help to mitigate the problem of user involvement.

However, achieving the goal G22 needs the deployment of both the marketing strategy S12 as well as the introductory training strategy S22. Likewise, achieving the goal G23 i.e., getting the registered faculty members to learn how to select a potential research idea, requires the deployment of three strategies namely, the marketing strategy S21, the introductory training strategy S22 as well as the specialized workshop strategy S23. Finally, the goal G24, which consists of submitting an acceptable abstract, introduction and the paper road map, from within the RSS system, requires the deployment of the three above-mentioned strategies S21, S22 and S23 in addition to the S24 strategy.

The strategies S21, S22, S23 and S24 which consist of the ADRESS marketing and motivation, training and advanced training strategies, can be implemented through the development of appropriate action plans, which depend on the organizational structure of the target institution. For some institutions, they may choose to impose the access to the institution research grants and promotions based on the active participation and skills acquired by the faculty members during the workshops of the ADRESS software. Moreover, the possibility of integrating the ADRESS software with a RMIS/CRIS, as it will be discussed in Section V below, enables the research management staff to follow up on the interaction of the faculty members with the system and thereby monitor the progress achieved by each user of the system.

C. LEVEL-3 DECOMPOSITION

Clearly, the strategy S11 i.e., "RSS general design and access strategy" is obvious to implement and depends on the software application development framework and therefore the decomposition will not proceed further from this leaf node. However, since it is not yet clear how to implement strategy S12, which consists of the search strategy for a potential research idea, the sub-goal G12, which pertains to facilitating the search for potential research ideas, must be decomposed into the following sub-goals (Fig. 7):

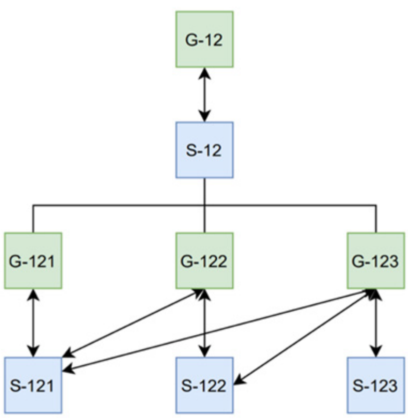

FIGURE 7. Level-3 decomposition of the goal G12: the double arrows illustrate zigzagging.

G121: "Facilitate the search for relevant articles"
G122: "Facilitate the search for collaborators"
G123: "Refine the research idea with collaborators"

and, the corresponding strategies can be formulated as follows:

S121: "effective search for relevant papers" strategy
S122: "search for collaborators working on the same subject strategy"
S123: "collaboration mechanism (for e.g. instant chat) for refining research ideas" strategy

The following equation relates the level-3 strategies to the three sub-goals of the parent goal G12.

$$\begin{bmatrix} G121 \\ G122 \\ G123 \end{bmatrix} = \begin{bmatrix} X & & \\ X & X & \\ X & X & X \end{bmatrix} \begin{bmatrix} S121 \\ S122 \\ S123 \end{bmatrix} \tag{6}$$

Equation (6) shows that in order to achieve the sub-goal G121 i.e. to facilitate the search for relevant articles, all is needed is the deployment of strategy S121, which consists of the effective search for relevant papers, independently of the other two strategies namely, the search for collaborators and the refinement of the research idea using collaboration. The strategy S121, which consists of the effective search for relevant research papers, cannot be readily implemented at this decomposition level, and therefore the corresponding sub-goal G121 needs to be further decomposed. It is noteworthy that S121 is crucial to the successful use of the ADRESS software, and has received considerable attention under the name "research paper recommendation techniques" [48]. However, the sub-goal G122, which aims at facilitating the search for collaborators, needs both the above-mentioned strategy S121 as well as strategy S122, which consists of the search for potential collaborators from the same institution as well as from other institutions working on the same research topic. Likewise, the sub-goal G123, which consists of refining the research idea with collaborators, all the above-mentioned strategies namely, S121, S122 and S123 need to be deployed. Likewise, the strategies S122 and S123, which consist of the search for collaborators and the collaboration mechanism, respectively, can be readily implemented using the techniques described in [57], [58], [59]–[61], and therefore they can be considered as leaf nodes in the decomposition tree. Clearly, the design matrix in equation (6) is lower triangular, it follows that the design is decoupled. Fig. 7 depicts the level-3 decomposition of the strategic goal G12.

Likewise, since it is not yet clear how to implement the strategy S13, which pertains to streamlining the publication process, it follows that the strategic goal G13 needs further decomposition into the following four level-3 sub-goals (Fig. 8):

G131: "Propose a title for the publication",
G132: "Write an abstract for the publication",
G133:" Select the keywords for the publication ",
G134: "Search for journals for the publication",
Along with the following corresponding strategies:
S131: "Title writing" strategy,
S132: "Abstract writing" strategy,
S133: "Keywords selection" strategy,
S134: "Journal search" strategy.

The following equation relates the abovementioned level-3 strategies to the four sub-goals of the parent goal G13.

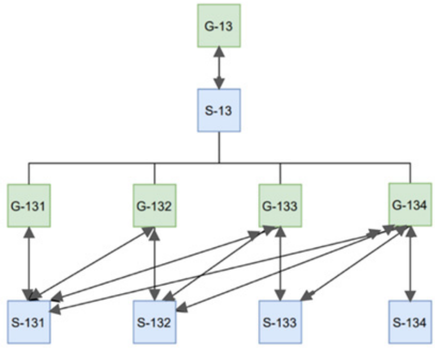

FIGURE 8. Level-3 decomposition of the goal G13: the double arrows illustrate zigzagging.

$$\begin{bmatrix} G131 \\ G132 \\ G133 \\ G134 \end{bmatrix} = \begin{bmatrix} X & & & \\ X & X & & \\ X & X & X & \\ X & X & X & X \end{bmatrix} \begin{bmatrix} S131 \\ S132 \\ S133 \\ S134 \end{bmatrix} \tag{7}$$

Since the design matrix is lower triangular, it follows that the design is decoupled. Equation (7) shows that in order to achieve the sub-goal G131 i.e., propose a title for the publication from the ADRESS system, only the title writing strategy S131 needs to be deployed. However, writing an acceptable abstract for the paper i.e. achieving the sub-goal G132, both strategy 131 and the strategy 132, which consists of writing an acceptable abstract need to be deployed. Likewise, in order to achieve the sub-goal G133, which pertains to the selection of appropriate keywords for the paper, the above-mentioned two strategies namely, S131 and S132 in addition to S133 need to be deployed. S133 being the "Keywords selection strategy". Finally, in order to achieve the sub-goal G134, which consists of selecting an appropriate journal for submitting the paper, all the three above-mentioned strategies in addition to the strategy S134, which pertains to the journal selection strategy need to be actioned. At this level, all the strategies S131-S134 can be implemented by following the implementation guidelines, described in the next section. Fig. 8 depicts Level-3 decomposition of the strategic goal G13.

Since most people read the title and the abstract of a paper, the strategy S131, which pertains to selecting a title for the paper, has been investigated in the literature across many research disciplines [63], [64], [70] and some journals give specific guidelines for writing the title for a publication [65]. Moreover, Keywords selection and the abstract writing strategies have been the subject of numerous research papers, which give guidelines on how to structure an acceptable abstract. Despite "Introduction, Methods, Results, and Discussion" IMRaD [68] being the most prominent structure of the abstract of a scientific paper, there is a myriad of discipline-specific standards such as those cited in [69]. Needless to mention that most journal editors [63] base their decision on whether to accept or reject the paper based on the title, abstract and keywords of the paper. Moreover, recent advances in natural language processing (NLP) and Machine Learning (ML) [71], [72], provide ready to use algorithms for the analysis of the title and abstract, thereby making them candidate software components to be incorporated in the ADRESS software. Finally, the search for the right journal strategy S134, can be implemented using the tips and guidelines discussed in [73]. Moreover, most journals provide interactive programs that can be used to locate the most appropriate journal [66], [67].

D. LEVEL-4 DECOMPOSITION

As discussed earlier, it is not clear how to implement the strategy S121, which consists of the search mechanism for relevant articles, therefore the sub-goal G121 needs to be further decomposed as follows (Fig. 9):

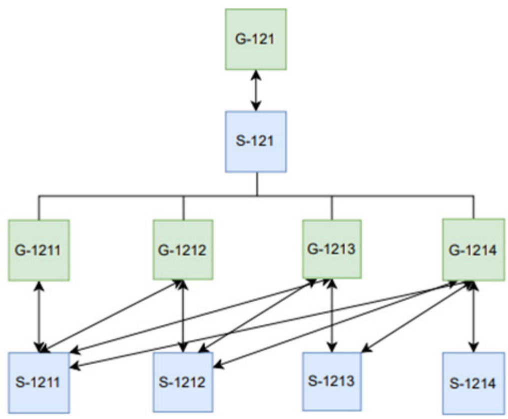

FIGURE 9. Level-4 decomposition of the goal G121: the double arrows illustrate zigzagging.

G1211: "search with user personalized potential keywords",

G1212: "search for papers with future research directions",

G1213: "search for review papers on the subject",

G1214: "refine the research idea",

and the corresponding strategies for G121 are:

S1211: "Search with user personalized potential keywords" strategy,

S1212: "Search for papers with future research directions on the subject" strategy,

S1213: "Search for review papers on the subject" strategy,

S1214: "Research ideas refinement" strategy.

The following equation relates the four level-3 strategies to the four sub-goals of the parent goal G121.

$$\begin{bmatrix} G1211 \\ G1212 \\ G1213 \\ G1214 \end{bmatrix} = \begin{bmatrix} X & & & \\ X & X & & \\ X & & X & X \\ X & X & X & X \end{bmatrix} \begin{bmatrix} S1211 \\ S1212 \\ S1213 \\ S1214 \end{bmatrix} \tag{8}$$

Equation (8) shows that in order to achieve the sub-goal G1211 i.e., to enable the search for potential papers with user defined keywords, only the strategy S1211 needs to be deployed. However, achieving the strategic goal G1212, i.e., finding papers with future research directions, both strategies S1211 and S1212, which consists of filtering the search results obtained with S1211 to include only the papers with future research directions need to be actioned. Likewise, in order to achieve the sub-goal G1213, i.e. the search for review papers, the strategies S1211, S1213 in addition to the specific strategy S1214 need to be actioned. Finally, the sub-goal G1214, i.e. refining the research idea, all the three above-mentioned strategies in addition to a specific mechanism for research idea refinement S1214 need to be deployed. Strategies S1211-S1214 are leaf nodes, as their implementation can be carried out using modern information retrieval techniques. Indeed, S1211 i.e., the search for relevant research papers can be performed using the keywords entered by the user, past research history or a combination thereof. However, searching paper collections this way, with search engines, is expected to produce a very large volume of results, which may be irrelevant to the user, regardless of the paper search engine used, and thereby the user spends much time to find relevant papers. Numerous alternative modern approaches such as collaborative filtering, graph-based recommendation systems, etc. to name a few, can be used to implement this ADRESS specific module. The strategy S1213, which consists of the search for review papers on the subject can be implemented using the techniques described in [74]. Finally, the last strategy S1214, which pertains to the refinement of the research idea, involves transforming the research idea to a precise research question by following standard frameworks such as FINER and PICOT [75]. Therefore, all the fourth level goals G1211, G1212, G1213 and G1214 are leaf nodes in the decomposition tree.

E. IMPLEMENTATION GUIDELINES OF THE PROPOSED AXIOMATICALLY DESIGNED RESEARCH SUPPORT SYSTEM (ADRESS)

Following the Axiomatic Design guidelines for developing software applications [18], the functional requirements found by the AD analysis represent the specifications, or requirements of the ADRESS software system modules (to be developed), the DPs are the inputs to the software modules and the Process Variables are the subroutines, machine codes and compilers. Thus, the leaf FR's found by our AD analysis in the previous section, represent the functionality needed in any implementation of the ADRESS software. The following section describes the architecture of the proposed research support system, where all the ADRESS modules are shown in the last column of Table 1, which depicts the general design matrix of the ADRESS software.

1) M1: ACCESS MODULE

Accessing the system by both the management, researchers and thesis supervisors depends on the web-based application programming framework, used in implementing the ADRESS application. Despite the ease of implementing access methods, accessing ADRESS must abide by some policies such as, the restriction of ongoing research activity to the researcher, authorized management, the student thesis advisor and department and college research committees.

Moreover, the collaborators must be registered in the system and authorized by the researcher.

2) M1211: SEARCH FOR ARTICLES

Due to the sheer size of the body of literature returned by searching with a given set of keywords, also known as the information jam, alternative efficient search paradigms have been under intensive investigations. The most prominent paradigm being "scientific paper recommendation systems", which includes filtering, collaborative filtering, graph-based recommendations, content-based and hybrid methods [48], [76]. A number of implementations of the above-mentioned methods, which can be adapted and incorporated into ADRESS, have been released in the open source domain. These packages include Surprise [77], Implicit [78], LightFM [79], pyspark [80], to name a few. Moreover, the BASE (Bielefeld Academic Search Engine) [81], containing more than 270 million documents, can be accessed by the ADRESS modules M1211 and M1212 using the provided BASE HTTP interface.

3) M1212: SEARCH FOR PAPERS WITH FUTURE RESEARCH DIRECTIONS

The search for articles with future research directions can be performed from within the ADRESS application by invoking a series of queries to a generic database application programming interface API, such as Google Scholar SERP API [82], [83], Web of Science wos [85], etc., or a domain specific data base, chosen by the user, such as BASE [81], PubMed [86] etc. The form of the query includes the user profile, in terms of keywords or past searches performed by the latter, in addition to and some specific keywords, such as "future research", "research directions", etc. The search results must be sorted in chronological order to facilitate the refinement of the research question of interest by the user.

4) M1213: SEARCH FOR REVIEW PAPERS

The search for review papers can be performed by querying publication databases with the user keywords embedded into specific forms of the query, which include the terms "systematic review", "review and synthesis" etc., in addition to the user profile, in terms of keywords, and past searches. Moreover, the search results must be sorted by date and citations count, which are automatically extracted by the present module, to allow the user to prioritize and screen out potential research questions.

5) M122: SEARCH FOR COLLABORATORS

The search for potential collaborators can be performed using social based recommender systems [57]–[59], [61]. The priority is given to researchers from different departments and colleges of the institution. The search results must also include the research profile of the potential collaborators, citation counts, etc.

6) M123: REFINE THE RESEARCH IDEA WITH COLLABORATORS

Refining the research idea with collaborators can be performed by providing a chat room from within the ADRESS

TABLE 1. General design matrix.

Functional Requirements (Strategic Objectives)			Design Parameters (Strategies): Data/ input to the objects															ADRESS Modules
			Secure access to ADRESS	*Potential idea search strategy*	Publication Process	Search for articles	Collaborators Search Mechanism	Search for potential papers with future research direction	Search with user keywords	Search papers with future research directions mechanism	Search review papers mechanism	Refine papers search mechanism	Communication with collaborators mechanism	Title Search mechanism	Abstract Write-up mechanism	Keywords Search mechanism	Journal Search mechanism	
Streamlined and secured access to the RIS system			X															ADRESS - M1: Access Module (Object)
Search for potential research idea	*Search for articles*	Search for relevant papers with user personalized potential keywords							X									ADRESS M1211: Search for Articles
		Search for papers with future research directions						X	X	X								ADRESS-M1212 : Search for Papers with Future Research Directions
		Search for review papers on the subject		X					X	X	X							ADRESS-M1213 : Search for Review Papers with Future Research Directions
		Refine the research idea							X	X	X	X						M1214: refine the research idea
	Search for Collaborators						X											M122: Search for Collaborators
	Refine the research idea with collaborators												X					M123: Refine the research idea with collaborators
Facilitate the publication process	Choose a title for the publication													X				M131: Choose a title for the publication
	Write an abstract for the publication													X	X			M132: Write an abstract for the publication
	Write the keywords for the publication				X									X	X	X		M133: Write the keywords for the publication
	Find a journal for the paper													X	X	X	X	M134: Find a journal for Publication

application, where the different search functions can be accessed online by all the collaborating parties. The chat session can be automatically recorded, and any changes made to the document during that session can be traced back for e.g., suggestion of further reference papers, etc. This will help building trust among users and thereby promote strong research collaboration.

7) M131: CHOOSE A TITLE FOR THE PAPER

The title of a publication must follow the target journal guidelines and instructions and therefore, it must be adjusted accordingly and automatically by the present ADRESS module. Since the title is used by search engines for indexation, the title must abide by some general rules and guidelines such as, the inclusion of the important keywords. The latter strategies contribute to increasing future citations count of the paper.

8) M132: WRITE THE ABSTRACT OF THE PAPER

The abstract of a paper must be concise, precise and structured to convey the research findings to a large audience of readers. Despite ''Introduction, Methods, Results, and Discussion'' IMRaD [68] is the most prominent structure used in writing the abstract of a scientific paper, there is a myriad of discipline-specific standards such as those cited in [69], which can be incorporated in the M132 ADRESS

TABLE 2. Implementation guidelines of the adress software.

Module	Input (DPs)	Output	References to Potential Methods	Notes
M1: Access to the ADRESS application	Secure access method to ADRESS (user name , password, etc.)	Access to the system (welcome page)	-	Restrictions on the access to the research work in progress
M1211: Search for relevant papers	search for relevant papers type query, keywords, user search profile.	Relevant papers/ references (in one the known styles e.g., APA) into the search basket	[77]-[81]	This is a basic module whose output (search results) varies with the user keywords, state and the type of the database
M1212: Search for papers with future research outlook	Search for papers with future outlook type query, relevant papers (M1211 output), search profile	papers/ references on the subject with research outlook (in one the known styles e.g., APA)	[82]-[83], [85], [86]	Requires M1211 to be invoked first and the results thus obtained are then filtered out
M1213: Search for review papers	Search for review papers type query including: keywords, search profile, currency and citation counts	Reviewed papers/ references on the subject (cited in each review found) (in one the known styles e.g., APA.) along with dates and citations count	[81]-[83], [85], [86]	Reviewed papers must be associated with their currency and citation counts
M122: Search for collaborators	Search for collaborators query (with preference) , keywords, user search profile	List of potential collaborators along with their research profiles, citations count	[57]- [61]	Collaborators from the institution (preferred), outside collaborators with pre-specified citation count
M123: Refine research idea with collaborators	Collaborator profile (along with restriction rules)	Paper draft update, contribution statistics	-	Access to search functions, refinement process
M131: Choose and refine the title of the paper	Abstract, keywords and journal	List of titles to choose from	-	General rules for writing titles are enforced, in addition to specific journal rules
M132: Write the abstract of the paper	Abstract format for e.g. IMRAD, restrictions (# of words), etc.	Abstract in the desired format	[68], [69]	General rules for writing abstracts are enforced, in addition to specific journal rules
M134: Find a potential journal to submit the paper	Tile, abstract and keywords, impact factor range	Potential journals along with templates and restrictions	[88], [89]	Constraints on journal Impact Factor, rank, etc. can be imposed by the user or the institution
M1214: Refine the research idea	Initial research question	Refined research question	[62]	
M133: Write the keywords	Paper title and abstract	Title, abstract and a list of potential keywords	[74], [87], [89]	

module. Moreover, recent advances in the development of algorithms for the analysis of the title and abstract, natural language processing (NLP) and Machine Learning (ML) [87], provide ready to use tools to improve the abstract of a paper. The implementation of this module can take advantage of the above mentioned structure by requiring the ADRESS user to explicitly write the text corresponding to each component, such as the introduction, methods, etc.

Table 2 summarizes the implementation guidelines of the ADRESS application modules along with references from the literature, which refer to potential techniques that can be used for their implementation.

9) M134: FIND A POTENTIAL JOURNAL FOR THE PUBLICATION

The search for a suitable journal to submit a paper at hand can be performed by matching the keywords and the subject classification of the paper with those of the journal. Another strategy consists in choosing from the journals where the cited references have been accepted for publication and sorting the results in accordance with their impact factor, rank, etc. Once the journal has been selected for publication, the user can upload the built-in journal template along with further specific instructions of the journal. Due to the large number and diversity of journals covering the research topic at hand, ''Journal Recommendation Systems'' [88], [89] have recently provided efficient and promising tools for identifying potential journals, and some tools are readily available from publishers [88], which can be accessed and used by ADRESS. Moreover, the management of the institution may restrict some journals from being selected by the system by imposing some criteria such as Impact Factor, journal rank, etc.

10) M1214: REFINE THE RESEARCH IDEA

Refining the research idea is the very first step towards a fruitful research project. It can be performed by the ADRESS system through supporting the researcher in the process of transforming the research idea into a precise research question [62]. This can be achieved by the repeated interaction with the modules M1212 and M1213. The most widely used frameworks in this context are FINER and PICOT, which were developed for medical clinical research [75] but can be extended to other research fields as well. This module allows the user to interact with the ADRESS application through formulating and querying successive research questions starting from an initial research question, until a satisfactory research question is achieved.

11) M133: WRITE THE KEYWORDS

The paper keywords or index terms are used by search engines to index the research document. A well-designed set of keywords enhances the visibility of the paper and thereby contributes to the future citations count, as it makes it easier for other researchers to find the research paper [74]. Moreover, Machine learning can be used to extract important keywords from the text [87], [89]. This ADRESS module supports the user in choosing the most appropriate keywords, which are compatible with the text of the paper and are visible to search engines thereby improving the citations count.

F. INTEGRATION OF THE ADRESS SOFTWARE WITH A RESEARCH INFORMATION SYSTEM

The research support system ADRESS, proposed herein, can be integrated with a RIMS/CRIS of the institution, as most of the latter systems have API's/wrappers [81], [82], [84], [85], which can be called by the programming language of the ADRESS modules e.g., Python, Java etc. An integrated ADRESS/RMIS will allow the management of all the research activities of the faculty and graduate students, especially at the very early research stages, and thereby provide detailed and valuable information regarding the progress, which can be used by the management of the institution to offer appropriate incentives and make informed decisions, such as lowering the teaching load, access to internal research grants, etc. Furthermore, upon receipt of the acceptance notification of the research work in progress, the proposed integrated system is immediately and automatically updated in accordance with the copyright transfer made by the authors to the publisher.

G. RECOMMENDATIONS FOR THE EFFECTIVE IMPLEMENTATION OF ADRESS

In addition to the efficient implementation of all the eleven modules comprising the ADRESS application, reaching the strategic goals and sub-goals, which were found by the AD decomposition, with high probability, requires the application of the AD information axiom [18] especially, the continuous and effective involvement of potential users in using the proposed system. In this regard, the four motivational strategies namely, S21, S22, S23 and S24 must be implemented under the supervision of the senior management of the public institution. Moreover, the integration of ADRESS with the institution RIMS/CRIS, discussed earlier, must be accompanied by the incorporation of key performance indicators to reflect the continuous research progress made by the users of the system.

V. CONCLUSION

Whereas most of the implemented RIMS/CRIS cover the research management life-cycle, starting from the submission of research works, our proposed Axiomatically Designed Research Support system ADRESS focus more on the research production life-cycle, towards boosting research at public universities. Towards this end, two sets of strategies were derived: The first set is in the form of software modules, which can be readily implemented following the suggested implementation guidelines. Some modules however, need further research and open new research directions, as no considerable attempts were made for tackling those issues.

Despite a few attempts to develop Research Support Systems during the past two decades, the latter systems have known only a limited success, due the lack of proven design methodologies. The proposed ADRESS system, which can be implemented as stand-alone application within the public institution or integrated with an existing RIMS, was derived by the application of the independence and information axioms of Axiomatic Design methodology. The added functionality, detailed in the previous sections, can be incorporated as a front-end software component into an open-source CRIS through customization. The resulting ADRESS- CRIS will cover both the research production and management life-cycles.

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