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An Analytical Comparison of BIM based MEP Design vs Traditional 2D Design, with BIM Level 2 Implementation Considerations

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Abstract − Building information modeling (BIM) and 3D software design tools have been proffered as a significant technical advance on traditional design methods for the mechanical, electrical and plumbing (MEP) sector. However, there seems to be contrasting BIM related information regarding its potential benefits, who gains from those benefits, and the best implementation methods for BIM Level 2. The purpose of this paper was to establish if implementing BIM 3D design softwares has some standalone benefits for a MEP design office still working in traditional design methods, irrespective of BIM Level 2. Once this was established, the paper investigated if 3D software design implementation could be an efficient first step towards the introduction of BIM Level 2 for a MEP design company. A mixed method research methodology was used. A literature review was carried out on traditional design methods, on BIM based design methods, and on BIM implementation methods and potential barriers. A design analysis comparison study was carried out on the design of a ducted heating, cooling, air conditioning (HVAC) system for an office building. The comparison of results generated from traditional design methods against those generated from the BIM design tool MagiCAD was carried out and analysed. Qualitative research was also carried out through interviews with a number of experienced MEP designers. Through triangulation of the data collected from these three research methods, the findings of this report were that BIM 3D design tool implementation offers many benefits to a MEP design office, whether considering full BIM Level 2 implementation or not. However, if 3D modeling was a good first step to BIM implementation was less clear. What was apparent however was that the proper managing and controlling of the steps to BIM Level 2 implementation is arguably even more critical than deciding on the actual first step.

Keywords – BIM, MagiCAD, Implementation, Traditional Design, HVAC

I Introduction

In any building, it's the Mechanical, Electrical and Plumbing (MEP) systems that bring it to life [1]. MEP is a term that refers to the design and management of the non-structural aspects of the building. Also referred to as 'Building Services', the MEP systems that are installed in buildings are designed to make the spaces comfortable, functional, efficient and safe. Building services includes energy supply and distribution, fire safety, IT networks, security systems, plumbing, heating ventilation and air conditioning (HVAC) to name but a few [2].

In a construction project, building services can account for 25% to 30% of the total project costs, increasing to 40% on more complex projects [3]. Building services design is tightly regulated by building regulations, energy related regulations etc. while project clients can also look for certification under schemes as Building Research Establishment's Environmental Assessment Method (BREEAM) [2]. Introduced in the United Kingdom in 2015, WELL was the first building standard exclusively geared toward wellness and human health, and key to this is an understanding of how lighting, water and air quality systems are a large part of the office environment [3].

It is during the design stage of a building that the building service systems are taken from conceptual to detailed design stages [4]. Consideration must not only be given to the desired outcome of the services, but also that it must operate within the rules and regulations previously mentioned. While there are opportunities for errors to be introduced during all stages of a construction project, it is at the design stage where errors have the largest potential to negatively affect a project, both in performance, cost and ultimately non-compliance with the regulations [5]. This report focuses on the design stage of building services, specifically on the ducted HVAC (heating, ventilation, air conditioning) system.

There are questions being asked by engineers in the industry of the traditional design methods that are based on the received wisdom of engineers that came before. Collins [6] believe that BIM (Building Information Modeling) design tools like MagiCAD can actually improve the accuracy of ducted HVAC systems, especially in terms of balancing the system.

Since the emergence of BIM, it has been unclear where the real benefits of BIM within building services lie [7]. The first aim of this research paper is to compare traditional MEP design methods against BIM 3D design tools. The research will then consider if the introduction of BIM software tools like MagiCAD into a traditional MEP design office might offer standalone benefits to the company irrespective of BIM Level 2 implementation. Perhaps some short and medium term returns without companies having to invest heavily in the software and training, while having to wait for the perceived long term benefits to come to fruition [8] [9]. Finally, the research will assess if these 3D design tools might provide an efficient first step to the introduction of BIM Level 2 into a MEP design company.

The structure of the remainder of this research paper begins with Section II, a short explanation of the research methodology used to carry out this study. Section III is the literature review of traditional engineering methods, and BIM based 3D design methods. The literature review also considers different recommended implementation methods that have been tried when companies have introduced BIM processes. Section IV is a design analysis comparison study of a ducted HVAC design for a typical office building. Firstly, traditional engineering methods are used to design a HVAC system, with 2D layouts created using AutoCAD. The same HVAC system is then designed and detailed in 3D using Autodesk Revit and MagiCAD. The results of these designs are then critically analysed. Section V gives a breakdown of the semi-structured interviews that were carried out with several MEP design engineers, all of whom are experienced in working in traditional engineering methodologies. They are also familiar with BIM 3D design softwares Revit and MagiCAD. The data gathered from these interviews are analysed in detail. Section VI is a section on discussions and findings. Section VII covers the conclusions of the research, with Section VIII giving some recommendations for possible future research.

II RESEARCH METHODOLOGY

This research paper is a qualitative study, using a mixed methodology approach. The research process began with the literature review of traditional 2D MEP design methods, along with the more recent BIM 3D design software tools. Advantages and disadvantages of both were considered. The literature review then focused on the possible implementation methods of 3D design and BIM design tools into traditional design offices, and potential barriers to efficient implementation. Subsequently interviews were conducted with MEP design experts who have experience of working in both the more traditional design methods, and also with 3D design tools, and as part of a team within BIM projects. The interviews were semi-structured, to encourage conversation and allow a range of feedback, whether positive or negative.

Finally, a design comparison study was carried out on the design of a HVAC system for a medium sized office building. Firstly designed using traditional 2D methods and using creating the 2D layout with AutoCAD. And then designing the same HVAC system in 3D using Revit and the design software MagiCAD. Through the in-depth interviews, in combination with the literature review and the comparison study, this paper critically compares traditional design methods against BIM 3D design methods, while also considering the issue of BIM implementation from a range of angles.

III LITERATURE REVIEW

a) Traditional Design Methods

According to findings from the National UK BIM Report [10] there is an increasing uptake of design engineers working in BIM and utilising 3D models and intelligent design tools. Thus meaning a shift away from the more traditional design methods and design engineers working in 2D environment. From the findings from the National UK BIM Report for 2018, it stated that almost 75% of respondents to its survey were using BIM, an increase of 12% on 2017 [10].

For traditional building services design, the methods commonly used can be categorised as follows: Rules of Thumb; Benchmarking; Tabulated or Graphical Benchmarks; Steady State; Steady-Cyclic [11]. The appropriate choice of the calculation method usually depends on the type of design being undertaken, the stage of the design, the information available and the risks involved. However, Collins [6] discusses growing concerns among engineers regarding some of the ‘tried and trusted’ traditional design methodologies. It has been reported that buildings are suffering from inefficient performance and unnecessary costs because they rely on design preconceptions rather than actually analysing how key systems and building services work [6].

Also, as more modern methods of carrying out design tasks are being developed, questions start to be asked of what has gone before

[12]. Many construction industry professionals have cited MEP coordination as one of the most challenging tasks encountered in the delivery process for construction projects [13]. With traditional MEP design, the coordination of services utilises the method of overlaying and comparing 2D layouts for multiple building service systems (usually created in CAD programs like AutoCAD), detecting and hopefully eliminating spatial and functional interferences between the MEP systems. These methods can prove time consuming, expensive, and are open to the potential negative effects of human error [14]. With MEP systems becoming more complex, with more sophisticated designs and complicated requirements of a building, the coordination of MEP systems has become a bigger challenge particularly in more complicated projects like multi storey commercial buildings where the requirements can be varied, specialised and bespoke [15].

b) BIM Enabling 3D Design Methods

BIM and intelligent 3D design modelling has been proffered as a significant technical advance on traditional CAD, offering more intelligence and interoperability capabilities [16]. BIM refers to a set of technologies and solutions that can improve collaboration and productivity in the construction industry, as well as improving design, construction and maintenance practices [12]. BIM design tools can provide improved platforms for parametric modelling, providing improved levels of spatial visualisation, simulations of building behaviour, efficient project management and collaboration of the construction team members [16].

Ghaffarianhoseini [12] highlights the importance of BIM-assisted design validation. BIM enables immediate and accurate comparison of different design options, which enables the development of more efficient cost-effective and sustainable solutions [12]. Research has confirmed that the impact of BIM on preventing schedule delays has the most influence on increasing return on investment (ROI) while rework preventions based on initial model validation / assessment is also a driver of BIM [17]. Research on ROI by Walasek [18] showed that design fees will most likely increase for design companies working with BIM. This is a result of more significant workloads occurring during the earlier phases of a project designed using BIMs collaborative methods [18].

Regarding encouraging designers to make the transition from 2D design in AutoCAD to 3D design in Revit, it has been reported that the project template in the Revit software has a larger role to play in the design process than in AutoCAD, it thrusts users into a more uniform industry practice instead of company specific solutions [19]. Project templates are the key to improving efficiency when working on a Revit 3D MEP project [20]. Bonduel [21] stated that the starting point of almost every successful software implementation is a good template created within the software. Revit, for MEP, is a design and a documentation tool, and designers whose role is to carry out design work should not have to spend time on issues other than achieving their design goals [20].

However, BIM does have some issues of its own. A potential weakness of BIM compared to traditional design documentation options is the possibility of 'false' information. When modelling in 3D, design software packages will supply default values for attributes that are used for calculating results if the user does not specifically supply them. This could lead to errors later in the project if users who access the model assume that the designers have intentionally decided upon these values [22]. In traditional design, the construction industry can operate from schemes and symbolic drawings rather than on exact 3D models. BIM modelling requires accuracy from the very beginning. Even the smallest mistakes in modelling objects or system elements could lead to major miscalculations and possibly result in major faults and designing complications [7].

Other challenges in the BIM advancement is the ownership of intellectual property and the cyber security of BIM designs [23]. Cyber security is a concern due to the possibility of online unauthorised access and copyright infringement [24]. Legal concerns also exist, problems with ownership of data or licensing issues. A research study was carried out on small and medium sized engineering companies in Ireland, and it was felt that there is an overload of BIM information out there and most of it is too difficult to understand for those not already familiar with BIM [8].

c) BIM and 3D Design Implementation

Regarding the implementation of BIM, there has been research done on both the most efficient ways of introducing BIM to a design office, and also on what some of the potential barriers to BIM implementation might be ([25], [16], [21]). A number of countries have developed successful implementation strategies with North America, the UK and the Scandinavian region arguably leading the way, with the importance of coordinated government support and leadership seen as a critical driver for BIM implementation [25]. Other important implementation strategies were found to be the development of both national and global BIM standards, BIM certification, legal protocols, training and education, while competitive advantage also provides a significant trigger for BIM implementation [16].

Lindblad [26] stated that in order to achieve successful BIM implementation, and make full use of its potential benefits, there is a requirement to understand how the implementation of BIM is reliant on carrying out the necessary changes in the organisation. Froese [27] also believed that in order for BIM to achieve its full potential, changes in the organisation, in the work practices and with the skills of the project participants are required.

Despite the huge potential for increasing productivity and the overall efficiency of construction projects, the adoption of BIM in Ireland has been observed as slower than expected [28]. According to the NBS UK BIM Survey [10], a survey on companies that are not working in BIM were asked what the main barriers to BIM were, and 69% of them said there was no client demand. Smith [25] believes that BIM implementation does require investment for the future. A potential issue with this is that many firms in the AEC industry, especially the small and medium sized firms (SME's), operate on a low profit margin which would inhibit their ability to invest in this technology for the longer term benefits [25]. This was backed up with a study carried out on SME's in Ireland. It was noted that some BIM guideline documents can be very complicated, and a simpler guideline to help SME's who don't have the resources of bigger organisations who can employ additional people to aid the implementation of BIM [8].

Other potential barriers that could hamper BIM adoption were found to be interoperability i.e. the development of BIM design tools for specific solutions and professions has resulted in a range of softwares that often do not interface properly with each other [29]. Another barrier was BIM actually matching the users requirements – there seems to be a lack of consensus on what BIM actually is [18]. Czmoch [7] felt an issue affecting the implementation of BIM is that BIM requires the users to get to know a large range of new expressions, phrases and jargon that are unfamiliar to designers who worked in CAD software used in traditional design. During the transitional period this can lead to different interpretations and misunderstanding of tasks and facts, potentially resulting in errors in construction projects [7].

Some other factors affecting BIM adoption in the construction industry were complicated BIM standards and protocols, a lack of support from senior management, a lack of interest or willingness in learning BIM, and the perceived costs of BIM [30]. However it is important to note that no one single barrier is solely responsible for hampering BIM adoption [18].

Adopting BIM is not easy, 94% of BIM users agreed that it has required changes in practices and procedures, yet only 5% wish they hadn't adopted BIM [10]. The longer firms delay their entry into the BIM world, the further ahead other firms with the BIM capabilities will progress and add to their competitive advantage [25].

IV DESIGN ANALYSIS COMPARISON

a) Setting up the Design Parameters

For simplicity of design this study was done on a relatively small single storey office building. The building had a variety of spaces – offices, canteen, toilet areas, meeting room, and a large reception area. For the purposes of the study, it would be assumed that there was a large void space above the ceilings to accommodate the large ductwork, and to allow the supply and extract ductwork to cross over where necessary. The building had an overall internal length of just over 22m, and an internal width of 12m, and uniform ceiling height of 3m throughout the building. Having a range of room types allowed this report to demonstrate the range of room requirements recommended by the CIBSE Guides [11] with regards to air change rates and noise criteria.

The next step in was to define a set of quantifiable design parameters that could be generated from the traditional design methods, and also from MagiCAD. The following were selected: size of round ductwork calculated throughout the system, and the pressure drop along the index run. Other areas also to be considered and discussed, although they would be more difficult to accurately compare, would be the time taken to create the design, the accuracy of the designs, and the quality of output information.

b) Traditional Design Method

In the traditional HVAC design method, the first calculations were to find the volume of each space in cubic metres. Next step was to refer to the CIBSE Guide for the recommended fresh air requirements for each occupied space. Older versions of the CIBSE Guides expressed the ventilation rate in terms of the number of air changes per hour [31]. However, in more recent publications of the CIBSE Guides, the air change rates are stated in the litres of air to be supplied per person per second [11]. However, the air change rate per hour is still a method used by all the traditional designers interviewed as part of this study, and so was the method used for the traditional design method. Once the number and locations of all grilles and diffusers were decided on, the routes of the branch duct work that joins the grilles and diffusers back to the main duct run could be detailed.

The conceptual sketch used to work out duct runs was the basis for both the 2D and the 3D methods for 2 reasons; 1) it ensured the duct runs would be similar and so the duct sizes calculated by both methods could be compared easily and, 2) regardless of which design method is used, it is still reliant to some degree on the engineering knowledge and experience of the designer to propose the most efficient duct routes and so it made sense to use the route from the conceptual stage. Table 2.16 from CIBSE Guide B2 [32] was used for the maximum velocity of the main duct run, the branches, and also the final duct feeding the diffusers.

Because these are the maximum recommended velocities, it is normal in practice to work to slightly lower velocities so that ducted systems are not designed at their limits. Therefore, for the calculations, the main duct run had a velocity of 5m/s, the branch off the main run had a velocity of 4m/s, and the duct runs to each diffuser and grille had a velocity of 3m/s. Once the air volume was known, and the air velocity was established, it was possible to calculate the duct diameter using the duct sizing chart. This also gave the pressure drop per meter length of duct in Pascals. See Appendix A for all calculations.

With the number of diffusers and grilles determined for each space, it was possible to calculate the duty of each individual diffuser and grille. Initially the study was planning on using the sizing nomograms for the diffusers. However, in practice the design engineer would use the manufacturers product catalogues when sizing the grilles and diffusers, so this was how the grilles and diffusers were selected. See Appendix B for all manufacturers sizing charts.

Finally, the pressure drop for the system was calculated. A rule of thumb mentioned by the participants in the interviews that is often used by HVAC designers to get a relatively good estimation of the pressure drop of a ducted system at conceptual design stage was applied for this calculation. This method allows 1 Pa per metre of duct to the diffuser furthest from the AHU. This is doubled to allow for all bends, reducers, dampers, branches etc. Finally, allow approximately 15-20 Pa for the pressure drop at the diffuser. The diffuser chosen in this case was the supply diffuser in the reception area. Because it was already known from the manufacturers data sheet that the supply diffuser would have a pressure drop of 15 Pa, and the extract grille would have a pressure drop of 10 Pa, that is what was used for these calculations. This duct run measured approx. 24m, so using the formula mentioned above, the pressure drop for the index run on the Supply duct would be 24 Pa (length of duct) + 24 Pa (fittings, bends, dampers) + 15 Pa (diffuser), which gives a total pressure drop of 63 Pa, while the pressure drop for the extract duct would be 5 Pa less because of the pressure drop at the grille, which gives a total pressure drop of 58 Pa. Once the design was completed, the ducted system was drawn up in 2D using AutoCAD 2014. See Appendix C for the final layout.

c) MagiCAD Design Method

The AutoCAD layout of the building was imported into Revit and used as the template to create the 3D model. It is worth noting that for the purposes of sizing the ducted system using MagiCAD, this could be carried out without the 3D model being required – the 2D AutoCAD layout could be used as a background. This was alluded to during the interviews as one of the benefits of MagiCAD, it is not reliant on the 3D model to calculate systems.

Once the 3D model was created, the grilles and diffusers were added into the different rooms as per the conceptual design. The volume of air associated with each supply diffuser or extract grille was inputted using MagiCAD to ensure that the total volume of the system would exactly match for both designs, allowing for accurate comparison of results. Next, the duct runs were added into the model. The duct runs were given the parameter of maximum velocity allowed; 5m/s for the main duct run, 4m/s for the branches off the main run, and 3m/s for the duct that runs up to each grille, which was the criteria for the traditional design. Again, this was done to allow the results to be compared with some consistency. Once the system was created, MagiCAD calculated the duct work sizes. See Appendix D for the final layout. MagiCAD also generated a Balancing report which confirms if the system can be properly balanced. A set of these MagiCAD reports can be found in Appendix E of this report.

d) Results

Once the MagiCAD duct sizing report and balancing report were created and exported, the design results were compared in terms of duct sizes calculated for each run of duct, and the associated pressure drops. The full table of results is shown in Appendix F, but in summary the breakdown was as follows;

d1) Duct Sizing Results

The Supply Air ductwork had 27 separate sections of duct sized; 7 sections of the main duct run (max air velocity 5m/s), 6 sections of duct work branching off the main duct run (4m/s), and 14 sections of duct connecting to the diffusers (3m/s). Out of the 27 sections of duct work sized, 23 were an exact match (85.19%), the remaining 4 were sized either 1 duct size up or down (note: HVAC ductwork is usually sized in multiples of 50mm, i.e. 150mm, 200mm, 250mm etc.). Analysing the 4 sections of duct that were sized differently, the duct sizes were actually on average only 15mm approx. from changing into the corresponding duct size.

The Extract Air ductwork had 33 separate sections of duct sized; 7 sections of the main duct run (max air velocity 5m/s), 9 sections of duct work branching off the main duct run (4m/s), and 17 sections of duct connecting to the grilles (3m/s). Out of the 33 sections of duct work sized, 23 were an exact match (69.7%), the remaining 10 were sized either 1 duct size up or down. Analysing the 10 sections of duct that were sized differently, the duct sizes were again on average only 15mm approx. from changing into the corresponding duct size.

d2) Pressure Drop Results

While the duct sizes calculated were very similar, the pressure drop calculations were less so. The pressure drops compared were the Pa per linear meter. On average, the pressure drop for each section of straight duct in the supply ductwork using the traditional sizing charts worked out at 0.827 Pa/m, whereas for the pressure drops calculated by MagiCAD the average worked out at only 0.483 Pa/m. The traditional method had a higher pressure drop of 0.344 Pa/m, which is a discrepancy of 41.6% which is quite sizable. There was an even larger discrepancy for the extract ductwork, where the traditional method had an average pressure drop of 0.94 Pa/m while MagiCAD had an average pressure drop of only 0.404 Pa/m. The traditional method had a higher pressure drop of 0.536 Pa/m, a discrepancy of 57%.

As part of the balancing report produced by MagiCAD, it calculates the pressure drop of the index run for both supply and extract duct runs. The traditional ‘rule of thumb’ method calculated a pressure drop of 63 Pa for supply, and 58 for the extract. The values from MagiCAD were actually very similar, coming out at 65.1 Pa for the supply, and 60.7 Pa for the extract.

The discrepancies were minimal, just over 3.2% for the supply and 4.4% for the extract. What is interesting here is that the traditional method would assumes the index run the duct run to the extract grille and supply diffuser furthest away from the AHU. For the supply air, MagiCAD calculated that the index run was actually the duct run to the last supply diffuser in the open plan office. For the extract air, MagiCAD calculated the index run was the duct run to last supply grille in the male toilets. MagiCAD calculating that the index run is not necessarily the grille furthest from the AHU supports key points made in the interviews, and also by Collins [6] in the literature review.

d3) Quality of Outputs

Arguably the quality of layouts from both the traditional 2D design and MagiCAD design is dependent upon the skills of the user. On the assumption the user is highly skilled using both softwares, it then comes down to the quality of output available using AutoCAD or MagiCAD. The output from AutoCAD, when used as a 2D design tool, was limited to showing the supply and extract grilles in different line colours, and the relevant annotation and data added in manually by the designer where required.

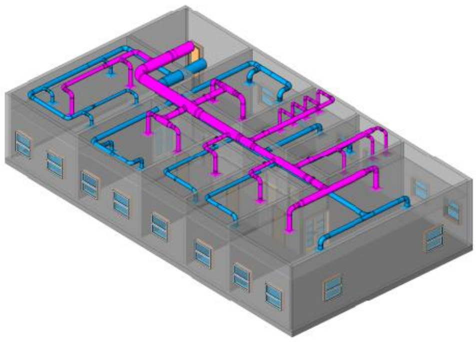

Fig. 1: The Revit model with HVAC system

MagiCAD has the options of creating numerous views of the same duct runs, in 2D and in any angle in 3D if required. It can produce colour coded layouts representing the different velocities of each of the duct branches, or based on air volume. MagiCAD can also produce on the layouts a number of schedules automatically generated from the model. These would have to be manually typed into AutoCAD. A huge advantage that MagiCAD holds here is that if the model is revised, the schedules all automatically update. For traditional 2D design, all schedules must be manually revised, leaving room for human error. This was a key benefit of MagiCAD alluded to both in the interviews, and in the literature review.

The MagiCAD balancing report even calculates to what extent each volume control damper (VCD) must be opened to balance the system. Finally, MagiCAD can generate a parts take-off list from the 3D model, which is of benefit to an M&E design office. It can create a very accurate bill of quantities, which would prove invaluable at tender stage when contractors are trying to price a project. Again, this was mentioned in the interviews as a big advantage when working in MagiCAD.

d4) Time Taken

The assumption was made that the designer is proficient in using both softwares. As mentioned previously, the basic calculations and conceptual designs that both methodologies were based on were carried out before the 2D layout or 3D model were created, so that was negated from the time taken.

To create the AutoCAD layout, and add in the annotation, notes, create the grille schedule etc. took approximately 4 hours. For the purposes of this study the model of the building was created in 3D, using the 2D AutoCAD layout as the base. As previously referred to, the designer has the option to create the HVAC design in MagiCAD without requiring a 3D model of the building. For this reason, the time taken to create the 3D model in Revit was ignored. If this was a BIM Level 2 project, the designer would have had access to a structural and architectural model to model the MEP services around. Allowing for this, the total time taken to create the full MagiCAD design was around 2.5 hours, 37% less than when working in AutoCAD. What could also be argued for here as another potential advantage of MagiCAD would be the time it would take to make revisions to the two designs if the project details were revised. This was mentioned by all participants in the interviews as another benefit of working in MagiCAD.

V INTERVIEW ANALYSIS

As part of the research for this report, interviews were carried out with four M&E design engineers, who varied in age, and in levels of experience. However, all had experience of working with traditional design methods, and producing layouts using AutoCAD. Also, they all had experience of working with 3D models using Revit, with the design software MagiCAD, and of working within BIM Level 2 projects. Each interview was semi structured based on open ended questions to help generate in depth responses. Each interview took approximately thirty minutes, they were recorded and transcribed, which yielded twenty-four transcription pages.

Table 1: Interviewees Experience

Reference:	Role:	Design experience:
Participant 1 (P1)	M&E Design engineer 3D modelling manager	5 years M&E Design Experience 5 years CAD experience 5 years Revit Experience 2 years MagiCAD Experience
Participant 1 (P2)	M&E Design Engineer Project Manager	11 years M&E Design Experience 11 years CAD experience 6 years Revit Experience 2 years MagiCAD Experience
Participant 1 (P3)	M&E Design Engineer Office Manager	17 years M&E Design Experience 17 years CAD experience 6 years Revit Experience 2 years MagiCAD Experience
Participant 1 (P4)	M&E Design Engineer Company Director	35 years M&E Design Experience 25 years CAD experience 6 years Revit Experience 2 years MagiCAD Experience

a) Traditional Design vs 3D Design

The first area of questioning focused on the designer's thoughts on the advantages and disadvantages of the traditional design methods, the use of 2D layouts etc. Some advantages and disadvantages of designing in 3D using Revit and MagiCAD were also discussed. Because of the nature of these questions, an advantage flagged for one methodology could be perceived as a disadvantage for the other, so a lot of the answers intertwined.

Regarding the advantages of traditional 2D design, all participants were in agreement that for smaller projects, or for early conceptual stages of a project, traditional 2D design methods are still useful. Some interesting points were raised regarding their thoughts on a designer having experience of traditional design methods before moving on to working in 3D design. 50% of the interviewees mentioned that the knowledge and skill set gained from design engineers having been trained and having experience of working in traditional methods are invaluable.

There were some disadvantages that they associated with the traditional 2D design methods. All participants mentioned that a recurring problem with traditional design, and working 2D layouts, is that the equipment schedules shown on the 2D layouts is not automatically linked to the 2D layout. These must be updated manually after every revision. The more revisions in a project, the higher the chance of conflicting information on layouts, especially when dealing with a number of building services. All agreed there is too much room for human error, each having experienced problems with information not being consistent.

This led into discussion on one of the major advantages of designing in 3D that was mentioned by all of the participants, that all the information is linked to the 3D model. If the model is revised in any way, all output generated from that model is automatically updated. One participant went on to state that this gives a higher sense of trust in the information generated from the 3D model, when compared to the data on a traditional set of 2D layouts which would be generated separately.

Following on from this point, 75% of the participants mentioned that revisions for HVAC system layouts, when detailed in 2D in AutoCAD, can mean starting the layout from the beginning again, which is very inefficient. This contrasts with revisions being carried out within the 3D models, which according to the feedback, is usually a lot easier, and quicker, to carry out. Another point raised by 50% of the participants was that they believed the achievable accuracy of the results generated from the duct sizing charts and diffuser sizing charts is not as accurate as results that could be generated from the 3D software.

A key point raised by one of the participants, and it was something very similar to an issue mentioned in the literature review by Collins [6], is the ability of MagiCAD to identify the index run of a ducted system. Identifying the index run, and the pressure drop along it, is critical for a ducted system. The participant explained that in traditional design methods, the index run is usually taken as the run of duct to the grille furthest away from the Air Handing Unit (AHU). But softwares like MagiCAD are now showing that this is not always the case. This correlates with some of the findings of the design analysis comparison that was carried out as part of this research, where the index run for the traditional method was taken as the grille furthest from the AHU. However, the MagiCAD generated results identified the index run to be a different duct run. The participant expanded even further into this, by flagging that the advantage of using MagiCAD to reduce the pressure drop across the HVAC system by running different design scenarios is invaluable. This type of design trialling simply isn't feasible with traditional design methods. This agrees with the findings of Ghaffarianhoseini [12] in the literature review.

One particular advantage alluded to during the interviews was very relevant to the research regarding the standalone benefits of the implementation of the software into a traditional 2D office. This was that MagiCAD MEP designs can actually be carried out without requiring a 3D Revit model at all, but by using a 2D layout as a backdrop. This could arguably make the transition to 3D design an even simpler step for the 2D design team. Some other benefits that were mentioned by the participants were the ability to generate an accurate bill of quantities from the model (75% mentioned this), the ability to coordinate with other services and with the building structure (100% mentioned this), and the quality and content of output from MagiCAD (75% mentioned this).

However, there were some disadvantages associated with utilising Revit and MagiCAD for MEP and building services design. Half the participants mentioned the set-up of project templates, object families etc. in Revit and MagiCAD is very time consuming when starting projects. A concern raised by 75% of the participants was that Revit, and MagiCAD, do use certain default inputs to generate results. If the engineer does not have the experience to recognise what all values and inputs actually are, errors could creep into the design and negatively affect the design results if the default value was incorrect. In traditional design, because all values are input manually into equations or charts, the designer tends to know what each value should be.

b) Implementation

After establishing the designer's thoughts on the traditional and 3D design methodologies, the questioning then focused on why Revit and MagiCAD were introduced to the design office, and how difficult they were to implement. The 'why' part of that question was straight forward. The participants stated that Revit was introduced into the company because it was a client requirement for a sizeable project. Their collective belief at the time was that 3D modelling was going to have to be introduced sooner or later into the office, so that project was the incentive.

MagiCAD, however, was implemented due to the necessity of the apparent benefits of utilising BIM 3D design software to create a more efficient design process. Again, a large project was the catalyst for the implementation, but this time it was not a client's request to implement MagiCAD, but the requirement to save time for the design team. Their belief, and they stated this has been proven to be true since its implementation, was that MagiCAD could generate calculations and size ducts and pipes quicker than traditional methods. One participant stating that it would not have been possible for the office to meet the deadlines on a project of that size simply using traditional methods to manually generate results.

The question regarding the difficulty of the implementation could be interpreted two different ways; 1) the difficulty of learning the software, i.e. the upskilling, and 2) the difficulty of achieving a successful implementation into the design office. Two of the participants mentioned that because Revit is part of the AutoDesk suite, and the desktops are quite similar, that this familiarity does help with the transition from 2D to 3D. In addition, because MagiCAD is an add on for Revit, the participants all agreed that once you were proficient in Revit, the step into using MagiCAD is an even easier transition. All participants believed there should not be any issues with the upskilling aspect.

However, as was shown in the literature review, the real difficulty with 3D design software implementation is rarely down to the upskilling in the actual software, and this was a strong theme from all of the participants. Having experienced the implementation of these softwares, the designers were asked what they felt might be potential barriers to the implementation of both Revit, and MagiCAD. They all agreed that the first key requirement for a successful implementation was the designer's willingness to make the transition. Without this, it would be difficult to convert designers, especially the more experienced designers who may be set in their 'traditional design' ways, from 2D to 3D design. A recommendation made by a participant was that the use of a BIM / 3D modeling champion in the office did make the transition easier.

Another issue mentioned by two participants was the initial lack of trust with the accuracy of results generated from implementing a new software. However, this was soon eliminated after some simple design results were carried out in both the traditional design method, and compared with the results generated in MagiCAD. One of the participants actually made the point that from this initial lack of trust, there is now an even greater trust for the accuracy of the results generated from MagiCAD than those created from traditional design methods of sizing charts, and rules of thumb. It is worth noting that this method of design comparison is very similar to the design comparison carried out in this research, and like the participants findings, the correlation between the traditional design results and MagiCADs results were impressive.

The designers were then questioned on whether implementing Revit and MagiCAD into a traditional 2D design office might have some possible standalone benefits, without focusing on the BIM Level 2 advantages. Many of the benefits already mentioned with implementing the software were mentioned again as standalone benefits, regardless of full BIM Level 2 being the aim. All four participants mentioned the information stored in one model giving the consistency of information. 50% of them said that modelling in 3D gave the reassurance that if something could be created in Revit and MagiCAD, it could be installed on site. The M&E bill of quantities take off was another standalone benefit mentioned by 75% of participants. They all agreed that the quality of output generated from MagiCAD higher. But the biggest advantage they all mentioned was speed – the efficiency of carrying out designs on projects. They do believe the larger and more complex the projects, the bigger the gains.

Finally, the designers were questioned on whether implementing Revit and MagiCAD might be an efficient first step of introducing BIM Level 2 into a traditional 2D design office. The feedback on this was mixed. One mentioned that if starting into the BIM Level 2 process and the first step was implementing the 3D design software, the software should first be used for smaller simpler projects, and under little or no pressure regarding time constraints or project deadlines. Or to simplify that further, they felt that by introducing MagiCAD and working on 2D templates in Revit, the designer could utilise MagiCAD for the duct and pipe sizing elements of a project without even worrying about 3D modelling in Revit.

Another Participant mentioned that a clever first step to introducing BIM Level 2, instead of starting with the software, could be to implement the file naming convention from PAS 1192-2 [33] on all current 2D projects. That way, when the 3D modeling gets introduced to the office, the designers would already be fully aware of what the correct file naming for BIM Level 2 was, instead of learning that in conjunction with learning the software. But there was one area that they all flagged as being a requirement for successful BIM implementation. The designer, and the design office, must have a willingness to transition into BIM Level 2. Without that, it is a struggle. Again, they had some clever ways around this. One participant mentioned that if you explained to the designers all the potential benefits that 3D design and BIM Level 2 would bring to them, i.e. time saved on creating and validating designs, the accuracy and consistency of information, the speed of creating bill of quantities etc. the designers should be more keen to learn.

A final point made by a participant was that they believed building services designers are entering a stage of serious design consideration. Mainly because of new legislation regarding specific fan power requirements in performance being a driver in HVAC system designs. Working in these tighter parameters, it was believed would be very difficult, and very time consuming, to trial optimum design solutions utilising traditional design methods. The participant added that they truly believe "the days are numbered" where it's acceptable to size ducted systems using traditional design methods of working to recommended velocities and pressure drops.

VI DISCUSSIONS AND FINDINGS

There were two overarching objectives of this study. Firstly, to investigate if BIM design tools could improve the MEP design process for designers still using more traditional design methods and working within a 2D environment. Secondly, to analyse if introducing BIM 3D design into a traditional design office might standalone benefits, while also be an efficient method of BIM Level 2 implementation.

Regarding the literature review, the researcher found that there was a large range of studies, journals and reports on BIM, its advantages and potential issues, and on methods of its implementation. However, there appeared a paucity of information available on the analysis of the more traditional design methods for MEP and building services. This put a greater focus on the interview feedback for the considerations of traditional methods. There was significant agreement of data collected from both the literature review and the interviews regarding BIM, which was reassuring as the study progressed.

Regarding the comparisons of traditional design methods compared to BIM enabling 3D design softwares, the research found there were advantages and disadvantages for both. Benefits were raised for traditional design in certain circumstances, and disadvantages of BIM 3D design were mentioned during the interviews and also in the literature review. However, the data gathered from both the literature review and the interviews does support the claim that there are far more positives than negatives when implementing 3D design into a 2D design office. This was further backed up by the design analysis comparison, which found that the 3D HVAC system design was created quicker, the pressure drop data was arguably more accurate, and MagiCAD generated a higher quality of output data.

After considering the merits of both design methodologies, this research moved on to appraise the benefits of MagiCADs implementation from firstly, a standalone perspective and secondly, as a first step for a MEP design office to transition into BIM Level 2. Analysing the data compiled from the literature review and the interviews, the benefits of 3D design and MagiCAD being implemented into a 2D office, regardless of BIM Level 2, were obvious. The speed of design, of rework due to revisions, the accuracy and consistency of the model, creating a bill of quantities, and the quality of the output from MagiCAD were all suggested as standalone benefits that could be gained from a design office, irrespective of BIM Level 2 Implementation. This correlated with the findings of the design analysis comparison.

The introduction of BIM 3D design as an efficient first step was not as evident. What was found from the literature review was that a change in organisation management and in work practices would be required for successful BIM implementation. This was expanded on in the interviews, where all participants felt that an unwillingness of designers to transition to 3D could undermine BIM implementation before it even started. A BIM champion in the design office would be recommended to promote BIM. Another suggestion made during the interviews was that an alternative first step to BIM implementation could be to introduce the BIM file naming convention even before 3D design was introduced.

VII CONCLUSIONS

For a research report trying to determine whether BIM enabled 3D design methods are better than what has gone before, in hindsight it would be difficult to deliver a definitive yes / no answer. A key point made in one of the interviews carried out was that the modern 3D design tools are still using traditional MEP design guides and methods, simply in a quicker more efficient way.

Also, the feedback from the interviews was that the experience and knowledge gained by a MEP engineer who has worked using the traditional 2D design methods is considered invaluable, whether working in 2D or 3D design methods. Considering the results from the literature review and the interviews there does still seem to be a place for the traditional design methods. Also, it appears from both the literature review and the feedback from the interviews that BIM still has issues that will need to be addressed before it gets the trust of those who are still to implement BIM Level 2.

But even allowing for all this, it is difficult to argue against the overall conclusions of both the literature review and the interviews, in conjunction with the results and output generated from the Revit and MagiCAD softwares. Implementing 3D design tools like MagiCAD would be a positive transition from 2D design. While BIM may still have issues to be addressed, it does seem inevitable that BIM 3D design is where MEP and building services design is gravitating towards, whether for standalone benefits or as a step in BIM Level 2 implementation.

3D design could become even more important as construction projects become more complicated, MEP systems become more complex, and the design regulations become even tighter. Because of this, the trialling of design options and the validation of whole HVAC systems will become a demand more than a ‘nice to have’. As stated in the literature review, traditional design methods are just too limited in terms of efficiency of output, and levels of accuracy achievable, and as mentioned in the interviews, the days are probably numbered for 2D design methodology.

Regarding introducing 3D design as the ideal first step for implementation of BIM Level 2 into a traditional design office, this seems to be less clear. Introducing BIM through 3D design is a realistic option, but it would have to be properly introduced and managed. According to the interview data, it seems that regardless of the exact method used to implement BIM Level 2, what is more critical is how that is managed. Once it is implemented through a controlled process, and introduced into a design team that believes in the benefits, it should be a positive step for a MEP design office to implement both 3D design tools, and BIM level 2.

VIII RECOMMENDATIONS

As mentioned already in this research, when analysing the results of the design comparison, it is difficult to assess the accuracy of one design against another, as they are both theoretical. What could be an interesting future study would be to get the commissioning reports from a fully installed ducted HVAC system, and carry out the design analysis of that system using both the traditional deign method, and also using BIM 3D design software tools, and compare the results of all three against each other.

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