DEVELOPING AN INTERACTIVE MODEL TO INTEGRATE HUMAN EXPERTISE WITH BUILDING INFORMATION MODELLING (BIM) SOFTWARE

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Cyril Kwasi Ahiable

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Civil, Construction and Environmental Engineering

April 2022

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Developing an Interactive Model to Integrate Human Expertise with Building Information Modelling (BIM) Software

By

Cyril Kwasi Ahiable

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Abdul-Aziz Banawi
Co-Chair

Jerry Gao
Co-Chair

David Crutchfield

Youjin Jang

Approved:

04/14/2022
Date

Xuefeng (Michael) Chu
Department Chair

ABSTRACT

Considering the significant amount of time and money wasted yearly in fixing errors caused by miscommunication and inadequate information on project sites, relaying the knowledge of field experts through design software may reduce communication-based conflicts in projects. This study aimed at creating a model to integrate human field expertise in the construction process with BIM software and also explored strides made in a similar regard. The study also explored the various strides made in human expertise integration. Basement construction in Fargo-North Dakota was the construction scenario selected for scrutiny in this study. Surveys and in-person interviews were conducted with local contractors to ascertain valuable recommendations on basement construction in Fargo. Information from these contractors was validated and coded into two concept models to offer warnings and recommendations on the assessed basement construction activities to help Architecture, Engineering and Construction (AEC) professionals with construction processes required before and during construction.

ACKNOWLEDGMENTS

I would like to express my sincerest gratitude to my advisor, Dr. Abdul-Aziz Banawi for his steadfast supervision and encouragement throughout my master's program. He taught and watched me grow and I credit all the new knowledge and skills I possess now to him.

My appreciation also goes to Dr. Zhili Gao. His input throughout my journey is immensely appreciated. Special thanks to Dr. David Crutchfield and Dr.Youjin Jang for their role on my committee. I am grateful to my family, for their continuous support, advice, and prayers.

DEDICATION

To God and my Parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
BIM	Building Information Modelling
AEC	Architectural, Engineering and Construction

LIST OF APPENDIX FIGURES

1. INTRODUCTION

The construction industry requires significant amounts of communication and collaboration between the parties involved (Gamil and Rahman 2017). The architects, engineers, project managers, supervisors etc. must be in constant communication for the project to be delivered efficiently. Over the years, technology has advanced in improving collaboration and communication in construction through the introduction and application of Building information modelling (BIM), Artificial Intelligence (AI) and other developments (Bock, T. 2015). These innovations have improved the construction workflow to some acceptable extent but there is certainly more room for improvement. One aspect that is lagging is the integration of human expertise with these available technologies (Ahiable and Banawi 2021) . If we agree that construction is heavily dependent on human involvement, one can argue that the quality of human expertise is vital to the construction process. Human expertise however is not the easiest type of data to integrate with computing (Pradier et al 2021). This is primarily due to its predominantly qualitative nature which requires substantial coding in order to be assimilated and implemented by computers (Pyke et al. 2010).

Human expertise in construction has been collected through interviews, surveys, and direct observation but the challenge with this type of data is its scalability and spatial interpretation. This means every information of this sort requires significant time and energy and can be hardly generalized or iterated. For integration of human expertise with modern technology, we need a systematic scalable feedback process which can be efficiently interpreted and executed in the computing world (Pyke et al. 2010).

1.1. The Importance of Human Expertise Integration

The uptake of modern technologies to improve cooperation between human and artificial intelligence in the construction industry has developed at a relatively slow pace (Takim et. al 2013). The construction industry has over the years undergone significant transformation and improvement in terms of labor application (Hamza et. al 2019). Manual labor required in construction for instance has witnessed drastic change as we tend to apply less of our physical strength and rather rely on machines and tools that execute labor usually in a more efficient manner. The cognitive aspect of construction has also seen a major change in operations. We have at our disposal, many software and tools to enhance design, planning, investigative, decision-making and other “cognitive-heavy” phases of the construction process (Sohn-Rethel 2020). Building Information Modelling (BIM) in particular has shown great potential in improving cognitive based processes in construction (Pan and Zhang 2021).

Integrating human intelligence with BIM will drastically increase our ability to detect, analyze as well as recommend viable solutions to problems we may face in actual construction. Construction is full of uncertainties and the more we can eliminate these uncertainties, the better the output. Construction processes are usually characterized by varying levels of unknowns (Yu et.al 2018). Collating the best practices for building processes helps Architectural, Engineering, and Construction (AEC) professionals gain a better foresight of what to expect on the ground especially in new locations (Banawi et. al 2020).

Project delays, unplanned costs and change orders are some of the effects of unforeseen situations. AEC professionals invest a lot of resources in preliminary investigations in order to reduce the risk of these undesirable outcomes(Abbasi et. al 2020). There are however situations that go unnoticed during the planning stages because they are underlying issues unique to the region that are not readily noticed by investigators and planners in effect. These situations are the kinds that merit human expertise. Expertise is mostly built with prior interactions with a particular situation (Eyal 2013). Field engineers, contractors, inspectors and other field personnel usually possess this type of expertise.

The need to complete a construction project with minimal risks (financial, safety, schedule) is always at the pinnacle of every AEC professional's target for the project. To ensure this, information that proves helpful in mitigating these risks are always in high demand (Gao et al. 2020). Construction best practices are a set of methods that aid in risk mitigation on a project. These are essentially the most appropriate and time-tested proven methods aimed at yielding better results in construction (Ahiable and Banawi 2021). This study embarked on a process to collect information from various sources in order to improve the quality of construction output. AEC professionals were crucial in gathering the most appropriate methods and practices within the construction processes. Structural, safety, cost, efficiency and ease of application were some of the major areas considered for scrutiny within the selected construction process. There are many ways to approach a job in the field and it is only the ones who have performed the job time and time again that have the ability to discern and decide on which methods are best suited for unique common and unique situations.

For this study, residential building construction was selected. Basement construction in Fargo was a subset within the residential construction process that was given priority as a small part of an extensive research. The goal of representing data from this study in a BIM model was to create an innovative method of data assessment and dissemination.

1.2. Problem Statement

Human expertise in construction, though acknowledged to be instrumental in project success, has not been adequately harnessed. The development of a means of storage and dissemination of human expertise on various construction processes is vital for its appropriate integration in the construction process thereby reducing potential associated risks. The application of BIM and AI can be instrumental in better integrating human expertise in the construction process.

2. LITERATURE REVIEW

2.1. Evolution of Construction Labor

Labor resources are an essential aspect on which the construction industry thrives (Jaillon and Poon 2008). Labor, as defined by S.E Thomas is the collection of human efforts of body or mind. Labor as a word can be classified into many categories: physical and mental labor, and unskilled labor, productive and unproductive labor (Shaikh 2017). All these labor types have their specific defining parameters. Physical and mental labor in terms of construction have their distinct requirements. Physical labor is any task that requires significant energy and physical strength and /or movement whereas mental labor has to do with tasks that require the exertion of the mind in achieving a task (Trevor 2019) . [1]

Throughout history, humans have always sought to improve efficiency of work while reducing labor effort significantly. The construction industry for example has experienced decades of labor evolution in a bid to reduce the amount of physical effort required to complete a task (Liao 2011). Bull dozers, tower cranes, excavators, graders, compactors etc. are just a few of the many innovations that drastically reduce required labor for the respective tasks. The mental labor requirements are equally substantial in terms of design, planning and project coordination for construction projects. A trend of mental labor evolution can also be seen with the gradual

---

[1] Ahiable C., Banawi A., Gao, Z., and Boateng S. (2021). To be submitted to ASCE *Journal of Construction Engineering and Management.* The material in this chapter was co-authored by Ahiable C., Banawi A., Gao, Z., and Boateng S. Cyril Ahiable had primary responsibility for conceptualization and research design, literature search, analysis, writing and revising the manuscript. Cyril Ahiable was the primary developer of the conclusions, drafted and revised all versions of this chapter that are advanced here. Boateng S., and Gao Z. proofread the entire chapter. Dr. Abdul-Aziz Banawi served as proofreader and checked and approved the analysis and model development conducted by Cyril Ahiable.

shift from physical pen and paper draftsmanship through numerous iterations of computer aided design technologies (Tornincasa and Di Monaco 2010).

BIM presents an invaluable opportunity for AEC professionals to integrate roles and deliver projects collectively in an efficient manner (Azhar 2011). BIM is a virtual prototyping technology and process which offers AEC professionals infinite (n-D) modelling capabilities (Azhar 2015). It supports integrated project delivery, a project delivery approach which integrates people, systems, and business structures and practices into a collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle (Farnsworth et al. 2015; Thurairajah and Goucher 2013; Masood et al. 2014; Glick and Guggemos 2009). Livingston and Azhar describe BIM as having limitless potential with respect to design, coordination and information sharing as opposed to 2-D CAD (Azhar 2015; Livingston 2008).

2.2. The Dependence of the Construction Industry on Human Expertise

The construction industry is one industry that is significantly dependent on human involvement throughout all the major phases including planning/design, preconstruction, procurement, construction, and post construction (KPMG 2015). It demands immense amounts of communication and collaboration between all parties involved. Eyal (2013) defines human expertise as self-acquisition of skills and capabilities to improve one’s effectiveness in defining an external reality. According to Friedson (2001), human expertise provides the self-governing human with the knowledge to delineate, control and adapt to various possible events within their professional scope which is why it is so crucial to the construction process. From the above definitions, we can coin a definition for human expertise in construction as the continuous gain of specialized knowledge essential for navigating various construction processes with the added advantage of minimized risk due to exposure and adaptation to similar events.

The amount and quality of human expertise involved on a construction project plays a significant role in the overall quality of project delivery in terms of cost, schedule, and risk management etc. (KPMG 2015). Even though human expertise in construction is acknowledged to be essential, it has not been appropriately integrated with the modern construction process (Pradier et al 2021). This may be partly attributed to its qualitative nature which requires substantial coding in order to be assimilated and implemented by computers (Pyke et al. 2010). The dependence of successful construction on human involvement cannot be overemphasized. In addition to the effective application of construction management tools and concepts, human factors significantly impact the processes of any construction project endeavor (Jaeger and Adair 2010). However, it will be inappropriate to rely solely on human factors to achieve quality construction. This is the reason for the several guidelines, manuals, codes of practice and standards provided by authorities in the Architecture Engineering and Construction (AEC) industry (Ching 2020).

Expertise in construction has been collected through interviews, surveys, and direct observation but the challenge with this type of data is its scalability and spatial interpretation (Dreyfus and Dreyfus 2005). Collection and Interpretation of such data can be time and energy consuming. For the integration of expertise with modern technology, we need a systematic scalable feedback process that can be efficiently interpreted and executed in the computing world (Pyke et al. 2010). The timeline for scholarly works concerning human expertise appears dated and is evident that more work needs to be done in that area.

2.3. Benefits of Merging Human Expertise with Artificial Intelligence/BIM

Human errors have been identified as one of the causative factors of poor construction (Kandregula 2020; Borgheipour et al. 2020; Tylek et al. 2017). Discretionary decisions are made during construction project delivery (Ghassemi and Becerik-Gerber 2011). These decisions may have unpredictable outcomes even though they are predicated on the knowledge and expertise of construction professionals (Cox III et al. 2008). The Construction process allows professionals to make certain decisions based on their expertise from practice (Ning et al. 2011). Nonetheless, these decisions when made must be guided by the acceptable practices of construction. To address the limitation of human errors, it is necessary to establish a synergy between human expertise, artificial intelligence and their related software programs. (Mcbride et al. 2014) intimated that computer programs and software have the potential to aid humans with a diverse set of tasks and support overall system performance. These technologies are designed to support overall system performance, assisting human operators with tasks such as information acquisition and processing, decision-making and action execution (Parasuraman et al. 2000).

Research has demonstrated that using perfectly reliable automation results in superior system performance as compared to manual performance (Moray et al. 2000, Dixon et al. 2005). These are assurances on how computer programs could be capitalized to enhance the construction process if reliable information is encoded into these programs. Finding the right balance between human involvement and computer program reliability is key since these programs also tend to commit errors. Computer programs and technologies such as BIM provide outputs based on input (Wang and Nokia 2009). This means they are not able to shuffle information to identify if the user has made some errors. This is a setback that prompts caution in the event of over-relying on a computer program to make all decisions. Ensuring the right construction practices are encoded into the computer programs is key to assisting the computer program in making accurate decisions. Maintaining quality standards in construction is essential (Gao et al. 2020). The human discretion in making certain pertinent construction decisions must be reduced to the barest minimum. Integrating expertise into BIM technology is a good way to improve the construction process. This will help professionals to make decisions based on tested construction practices. When human judgment or expertise, guided by best standards of practices, is encoded into a computer program software, the potential of achieving optimum construction project delivery could be improved (Banawi et al. 2020). From the above literature, it is evident that strides have been made to improve the construction process through technology.

Labor requirements have been minimized for many processes through innovative machines and software. Studies on the integration of human expertise with these available technologies is however relatively scarce. This study aims to integrate human expertise in the form of field expert recommendations with technology in an attempt to extract more use from this essential component of the construction process. To achieve this, the authors sought to collect recommendations on the best practices on specific construction practices from field experts and relay this through software usually applied during the construction process. These recommendations are what we term human expertise in this study as they were sourced from field experts who have been repeatedly exposed to various scenarios peculiar to basement construction in Fargo. The data collected will then be relayed through BIM software to designers about the construction subject.

The objective behind this process is to capture construction field expertise to provide warnings and suggestions readily to professionals to help with design, planning and decision making. The human field expertise provides a backdrop of field knowledge that can be compared with theoretical concepts to ensure synergy.

2.4. Analysis on the Progression of Human Expertise Integration in the Construction Industry

This study adopted a predominantly meta-synthetic approach where multiple qualitative research studies were evaluated, and findings interpreted based on the subject of human expertise integration in construction. This method was adopted because it fits the general inductive approach best suited for the type of data collected in this study. An inductive approach requires the condensation of raw textual data into summaries and establishing links between the evaluations and research objectives. Since this paper focuses on reviewing a broad range of prior work concerned with human expertise and construction, the inductive research method with meta-synthesis was appropriate. Owing to the relative rarity of literature on this subject, the search was not limited to a specific period in order with the earliest selected study dating as far back as 1991. This was to ensure an exhaustive review process.

Giving this, the requirements to qualify an article for selection were: 1. The articles must be peer reviewed, 2. The articles must contain specifics on human expertise and construction 3. The selected articles should highlight methods attempted for the integration of human expertise in construction. The words “Experience” and “expertise” were used interchangeably in the search string to ensure potentially all-inclusive search results. A timeline was designed to summarize the reviewed information for clearer perspective on the progression of human expertise integration. The chart in **Figure 1** summarizes the search, selection and analysis process.

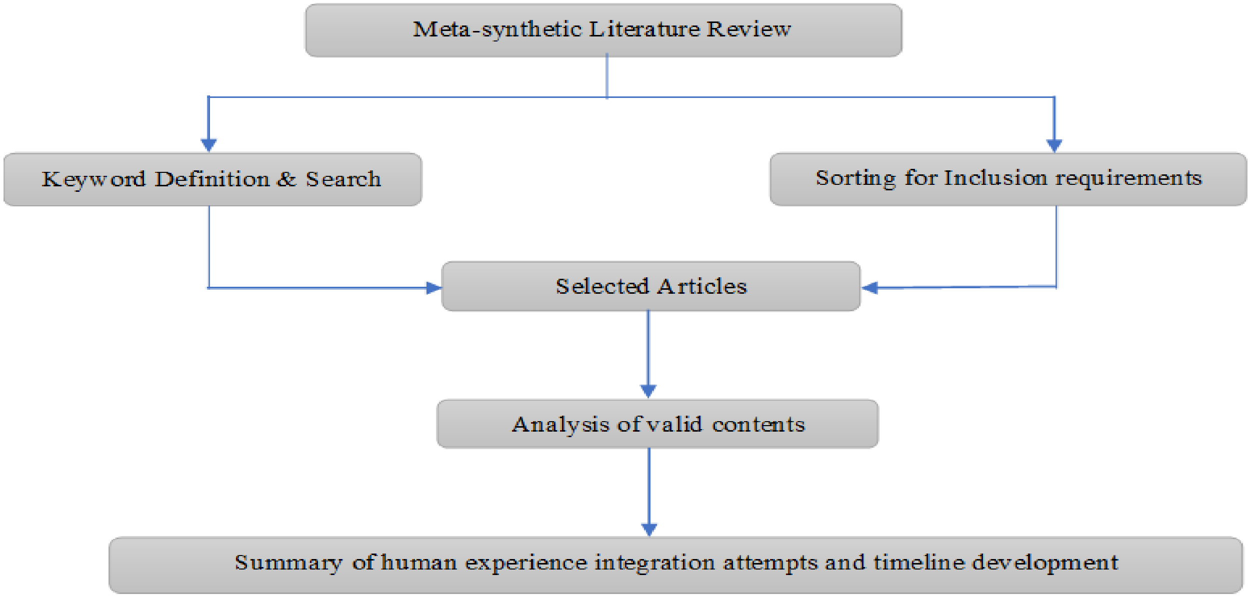


Figure 1. Schematic representation of analysis and summary methodology.

According to Eyal, G. (2013), human expertise stems from the self-acquisition of skills and capabilities to improve one's effectiveness in defining an external reality. Sociologists for a long time have worked in understanding the entirety of the concept of human expertise. Friedson, E. (2001) supports the above definition by adding that human expertise provides the self-governing human with the knowledge to delineate, control and adapt to various possible events within their professional scope. The study of human expertise set the stage for enquiries into other possible forms of expertise and their possible usefulness in the grand scheme of improving human abilities. Feigenbaum, E. (1992) on his work on expert systems initiated the development of "expert systems" which are simply rule-based computing programs designed to out-perform humans in terms of decision making and problem solving. The introduction of this idea was a good basis for the development of more sophisticated technologies in achieving this goal. Dreyfus, H. and Dreyfus, S. (2005) in comparing these expert systems with human expertise discovered a challenge these expert systems have. The limitation of these expert systems is in the fact that they are rule-based. The uniqueness of human expertise is the ability to rely on prior knowledge and adapt to relatively new real time situations. These expert systems can only perform within the confines of the algorithms upon which they were built.

Sage, D. J. (2016) in his piece on “construction expertise and posthumanism” provided fictional examples on how these expert systems fall-short of actual human expertise on construction projects. One example explained how an automated brick-laying machine may not be able to discern the adequate textures and gradients outside the command fed into it while a human expert can adapt and make the necessary adjustments per the conditions present. A look at the timeline of the progression of human expertise integration shows a steady increasing trend of the incorporation of three main apparatus: Expert Systems, Building Information Modelling (BIM) and machine learning. Eventually, BIM became all-encompassing as the idea of expert systems slowly disappeared. Since the introduction of expert systems by Feigenbaum, 1992, Alkass, S., et. al, (1996) sought to improve on this concept by introducing techniques to aid these expert systems minimize delays through efficient scheduling. The study created a model called the Isolated Delay Type (IDT) which can be used individually or integrated with Computerized Delay Claims Analysis (CDCA) systems. Chan, A et.al (2001) developed a multi-attribute model with the Delphi technique which sought to improve the selection of procurement systems. This was another variant of the integration of human expertise with systems in the construction industry. The study found that the Delphi technique was useful in detecting the right procurement system objectively.

Another instance was the integration of human expertise for subcontractor selection by Okoroh, M. and Torrance, V. (1999). In this study, a knowledge based expert system was implemented to create a user-friendly interface for subcontractor selection. With time, BIM became more popular and integrated all these separate expert systems through add-ons and plugins. The evolution of BIM alone illustrates a steady attempt in integrating human expertise with construction computing software. BIM alone is still predominantly dependent on human manipulation and is not necessarily an independent decision-making process. Experts have begun to explore the extents of other technologies like machine-learning with deep learning and neural networks.

Human beings have an insurmountable ability to apply general knowledge in problem-solving situations for specific cases. Where human ability falls short is in the analysis of large numbers of scenarios occurring simultaneously Arciszewski, T., and Rossman, L. (1992). This is where computers fortunately come in where they excel in a process called induction which involves the use of machine learning to produce decision rules from prior decision examples. Currently, the application of machine learning is largely in constructability analysis, safety, and material property prediction. This has been achieved by coding a large amount of human expertise data into software programs to be applied on the field. Tixier, A et. al (2016) looked at the application of machine learning in injury prediction on construction projects. The study made significant progress in providing reliable probabilistic predictions on injury severity and outcomes of accidents on construction projects. Erdal, H. (2015) examined the integration of human expertise with machine learning technology to predict the compressive strength of materials and concluded that high levels of accuracy were achieved with the combination of neural networks and support vector machines (SVM's). The timeline in the **figure 2** was created to summarize the progression of attempts in integrating human expertise in construction based on the reviewed articles.

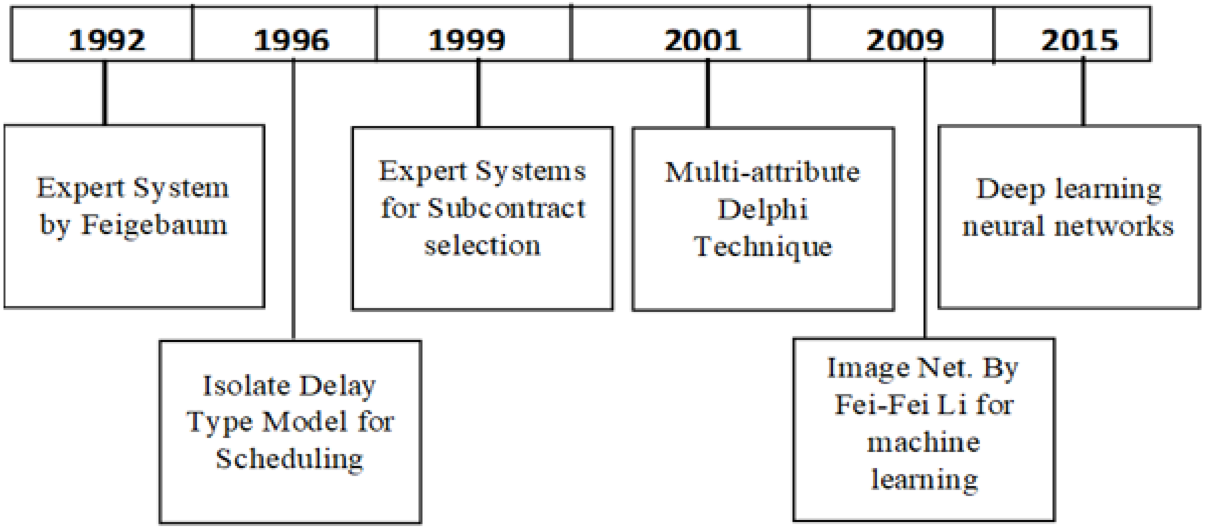


Figure 2. Timeline of the milestone attempts at integrating human expertise in construction.

As discussed in this section, efforts have been made to apply computing systems in various construction processes. However, there has not been significant studies concerning the integration of actual human field expertise in construction with the use of any available construction technology. The following section elaborates on the methods employed to bridge this important gap.

3. METHODOLOGY

In response to the stated research gap, this study explored feasible paths to integrating human expertise with BIM software with concepts of model development. The first concept was developed with a Revit®-Dynamo combination and the second developed using Visual Basic software. This study was conducted in the following steps: (i) Data collection and analyses, and (ii) Model Development and data integration. **Figure 3** is a schematic representation of the research approach for the model development.

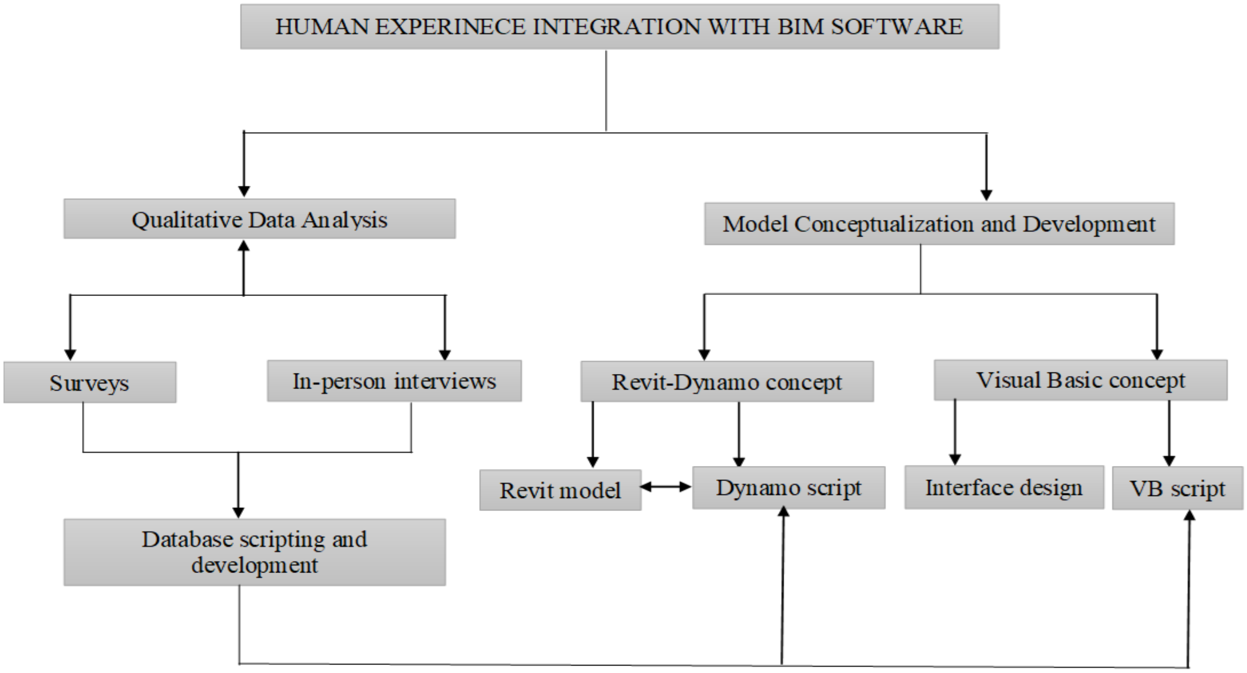


Figure 3. A schematic representation of the research methodology for model development.

3.1. Data Collection and Analyses

A purposive sampling method was adapted for the surveys. Close-ended surveys were created with Google Forms specifically for home owners and contractors and distributed online to ascertain some issues concerning basement ownership for home owners and construction processes for contractors, respectively. Concerning home owners, the survey took a more generalized nature and was structured to collect information such as basement type and use, basement maintenance cost, basic structural dimensions, and the problems they face with basement ownership, among others. The responses from home owners were vital in modelling a typical basement in Fargo, ND, USA for the study. The survey for the contractors was relatively more specialized and was primarily concerned with the intricacies involved in basement construction, especially in Fargo. The survey responses, especially the home owners, were used to gather some perspective for developing salient interview questions for local construction experts. This was to ensure that experts speak on the significant issues and their associated best practices. The surveys were distributed online with 20 home owners responding. This sample size though small, was enough for the purpose of the surveys as stated. Based on the survey responses to some indicative questions, a focus group of ten local construction experts including supervisors, contractors and inspectors was created.

The criteria for contractor selection were based on specialty and a minimum of five years of local expertise to ensure confidence in their recommendations. In-person interviews were conducted with these local contractors for further details on basement construction such as general practices, common errors, remedies as well as preventive measures. Basement construction in Fargo was chosen as a scenario for study because basement construction presents certain peculiar construction challenges (Tan and Chow 2008) and coupled with the harsh winter climate in Fargo, the authors postulated that the local field experts may have some information on adaptations required to navigate the construction process. This process was particularly helpful because they (the contractors) were able to divulge some good personal construction practices that they would readily recommend for the construction of basements in Fargo.

Information from the local contractors represent the human expertise intended to be integrated with BIM software.

The knowledge of these experts were classified according to the associated building processes involved in basement construction i.e. excavation, concrete works, insulation etc. The information received was validated with article 18-09 of the Fargo, North Dakota code of ordinances before applied in the study. In addition, a safety expert from the Occupational Safety and Health Administration (OSHA) was interviewed for general recommendations on safety in construction. Details on general construction safety practices expected by the agency and its inspectors were made known with adequate consideration given to basement construction. A database was built based on the information collected from the interactions with the local contractors.

The basement of a residential building was prioritized for this study because, basements are usually costly and possess high embodied energies. The reason why basements are capital and energy intensive is because they are primarily made up of retaining walls- a foundation structure. Construction of various foundation structures consumes a large amount construction material (Zastrow et al 2017). This could be translated to a high embodied energy (Inui et al. 2011). Basements have long been a design feature in many buildings, and they provide storage space for utility or in some cases, an extra living space. Analyzing and improving this aspect of construction will have significant upturns in building performance and construction processes making this a good area to start investigating.

Fargo, North Dakota was selected based on a few factors. To begin with, many residential homes within the town had basements. Surveys distributed to home owners further asserted this claim. The climate in the region was another compelling factor. Winter in Fargo presents some of the harshest conditions for construction and to be able to deliver projects successfully barring all the challenges is a feat to be studied and lauded. Basically, collating the best construction practices within the harsh climatic conditions is a good point to start. In addition, Fargo is also a relatively developing city in a state that is experienced a relatively recent economic boom. The U.S. Census Bureau published in 2018 that housing growth in North Dakota is the fastest growing in the nation at 18.9% (U.S. Census Bureau 2018). Economic development and expansion is almost certainly accompanied by increased construction activities in order to accommodate the growth in population and transactions (Alagidede and Mensah 2018). Assessing how things are done in a relatively developing state presents the opportunity to improve current methods so as to begin a trend/culture of good construction practices. This will aid in reducing the adverse effects construction has on the environment.

3.2. Model Development and Data Integration

The concepts considered for this study informed the authors decision on the most viable software to use in developing the respective models. The authors went through several iterations in the selection of the most suitable programming language for the model concept development. Autodesk Revit® was chosen amongst other design and visualization software due to its compatibility and easy integrability with third party programs. Dynamo was chosen to work in tandem with Revit® because it is innately part of the Autodesk package and hence compatibility was relatively more straightforward. Visual Basic as a program does not originally fall under the BIM software umbrella but was essential in fabricating the authors idea of a standalone model which can recommend construction practices based on a database of human expertise. Also, Visual Basic allows for the simple creation of the model interface and codes in an easy-to-use graphical environment.

3.2.1. Concept 1: Revit-Dynamo Model

This model type was developed in three main stages: (1) Revit® model development, (2) Linking Revit® model elements to Dynamo, and (3) Coding local expert recommendations into Dynamo nodes for Revit® model. The significance of the Revit® model is to create a focal project around which coding concepts can be evaluated. The model (**See Figure 4**) was developed from the building plans of a built 3-bedroom single family home with a basement. The basement elements of this model where the focus as basement construction was the scope for the interview with local construction experts. Building the model based on a Fargo home building plan and home owner survey responses was a good way of simulating a design process to be integrated with human expertise.

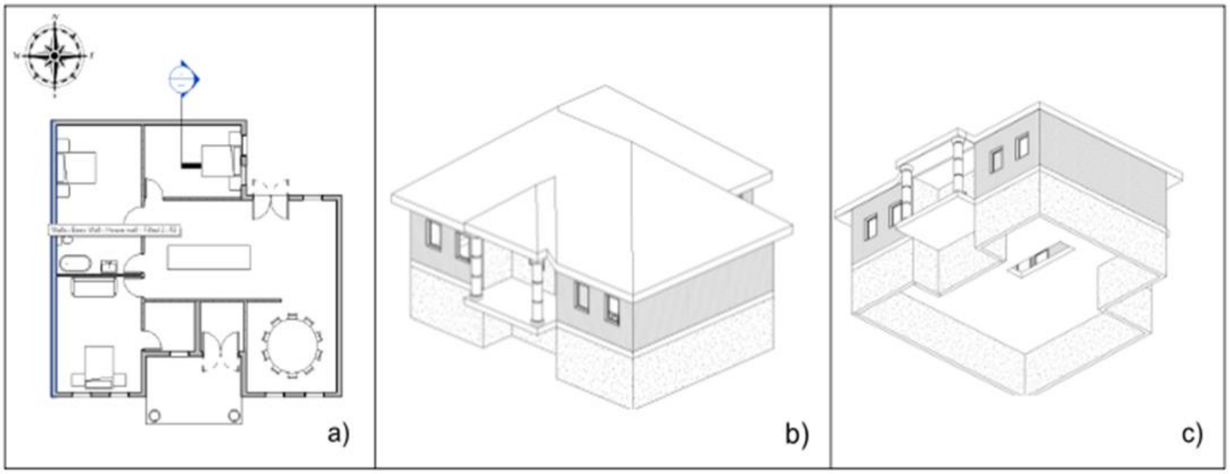
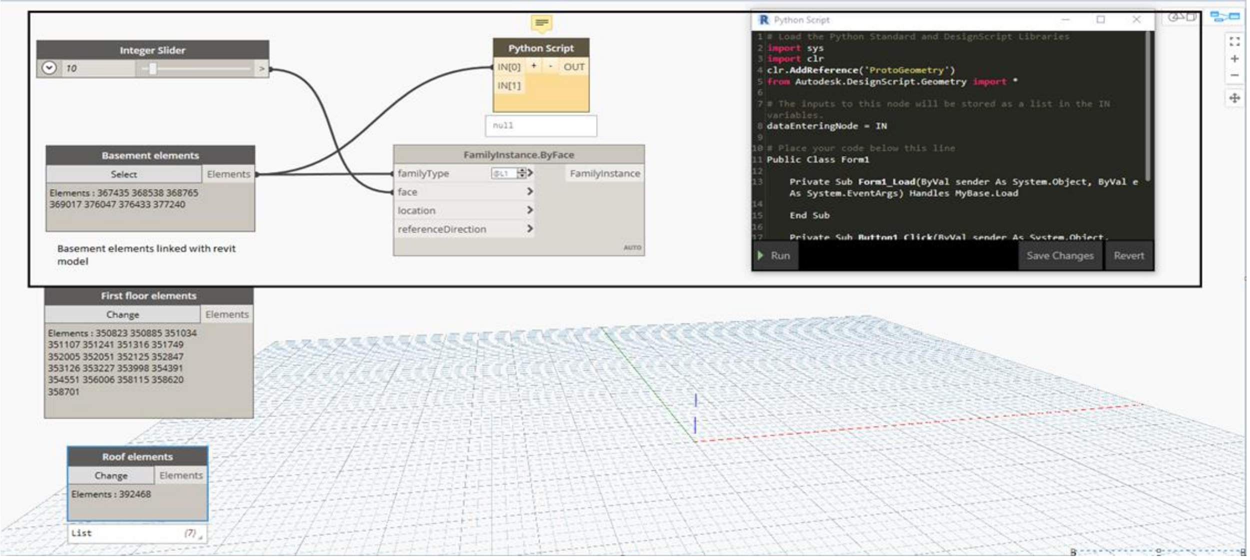


Figure 4. Floor plans and Isometric views of Revit model.

The individual design elements in Revit® were linked to Dynamo. Dynamo is an open-source visual programming that allows the extension of the parametric capabilities of Revit® (Asl et al. 2015) through which commands can be coded to control Revit® elements. The recommendations from local experts were coded as restrictions to the Dynamo nodes. This allowed the Revit® model to be compared with certain design restrictions in Dynamo which triggered respective recommendations once a design choice does not align the expert recommendations. For example, the depth of footings recommended by the field experts to guard against frost heaving was scripted as a restriction in dynamo. This prompts a warning pop-up when the user chooses a depth contrary to the recommended depth. The user however has the choice to carry on with the desired design depth as this pop up only serves as an extra layer of information which may be essential to the designer. The Dynamo workflow with the human expertise scripted in python is illustrated in **Figure 5**.



Elements : 367435 368538 368765 369017 376047 376433 377240

Basement elements linked with revit model

Elements : 350823 350885 351034 351107 351241 351316 351749 352005 352051 352125 352847 353126 353227 353998 354391 354551 356006 358115 358620 358701

Elements : 392468

```
# Load the Python Standard and DesignScript Libraries
import sys
import clr
clr.AddReference('ProtoGeometry')
from Autodesk.DesignScript.Geometry import *

# The inputs to this node will be stored as a list in the IN variables.
dataEnteringNode = IN

# Place your code below this line
Public Class Form1

    Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles MyBase.Load

    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object,
```

Figure 5. Schematic View of Revit® Model Elements Linked in Dynamo with Python Script.

3.2.2. Concept 2: Visual Basic Model

This model type was developed in two primary stages: (1) Interface design, and (2) Scripting of human expertise data for interface elements i.e., buttons, active fields etc. This concept is a standalone model type designed to operate individually unlike the Revit®-Dynamo model concept. The Visual Basic model is an illustration of how an independent fact-checking software delivering human expertise could operate. The interface was designed to be as simple and user-friendly as possible. The inputs of the model include the project location by state, project type (i.e., residential, commercial, or industrial), location, as well as date of construction as this is a fair indicator of potential climatic conditions and associated geological changes to anticipate. In a state like North Dakota, winter conditions present harsh working situations, especially in construction. As such, most of the recommendations from field experts in Fargo were based on ways to avoid or solve issues caused by the winter conditions. In this study, the outputs for the visual basic model are the recommended practices for the associated basement construction processes within the Fargo area. Unlike the Revit®-dynamo model, this model lists all recommendations at once rather than the individually triggered warnings. These recommendations appear in a list form when the user clicks the 'See recommendations' button. See **Figure 6** and **Figure 7** for illustrations.

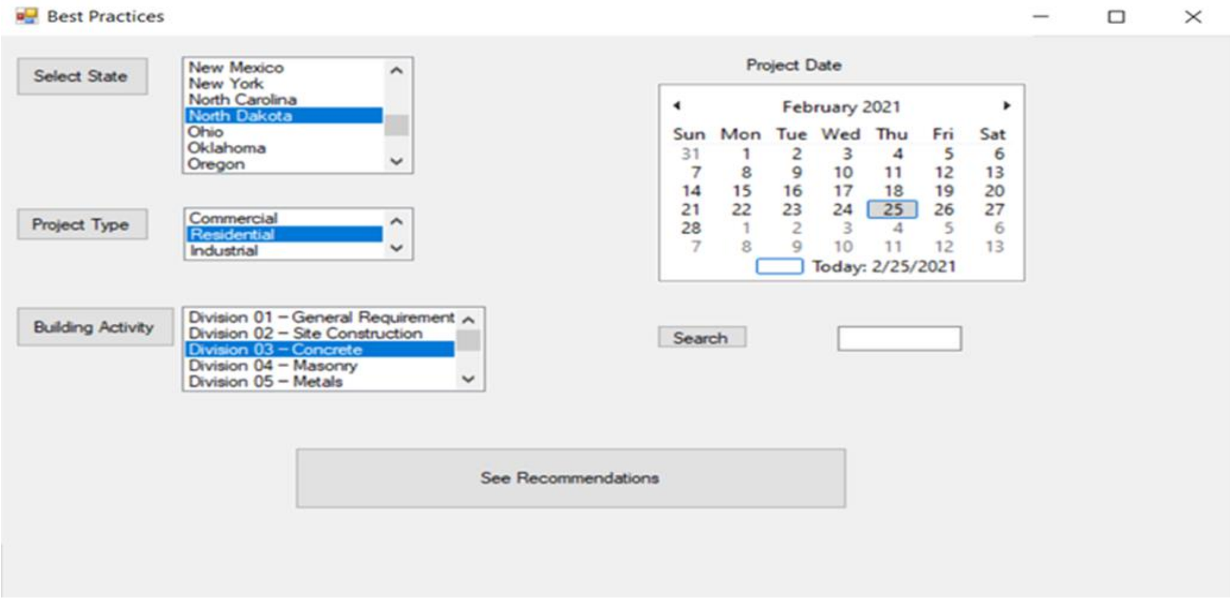
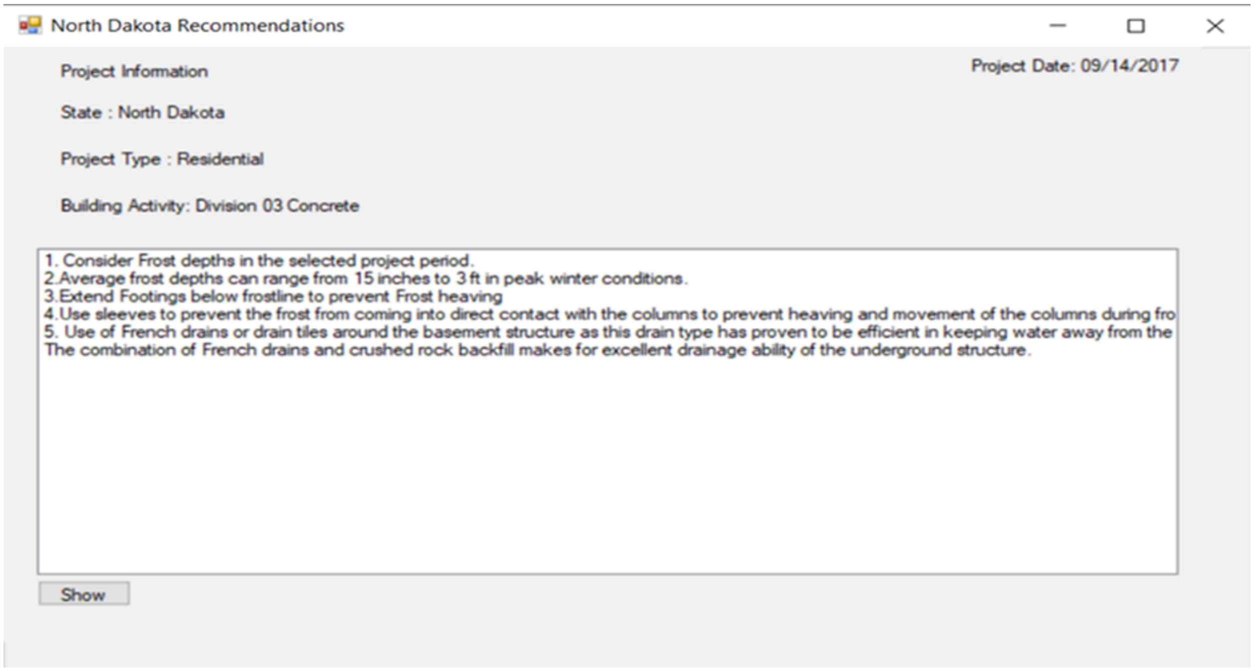


Figure 6. Screen 1 of Visual Basic Interface showing the selection screen with required inputs.



Project Information

Project Date: 09/14/2017

State : North Dakota

Project Type : Residential

Building Activity: Division 03 Concrete

1. Consider Frost depths in the selected project period.
2.Average frost depths can range from 15 inches to 3 ft in peak winter conditions.
3.Extend Footings below frostline to prevent Frost heaving
4.Use sleeves to prevent the frost from coming into direct contact with the columns to prevent heaving and movement of the columns during fro
5. Use of French drains or drain tiles around the basement structure as this drain type has proven to be efficient in keeping water away from the
The combination of French drains and crushed rock backfill makes for excellent drainage ability of the underground structure.

Figure 7. Screen 2 of Visual Basic Interface displays a list of local expert recommendations.

3.2.3. Justification for Software Selection for Study

The software used for this study include Visual Basic, Autodesk Revit, Autodesk Dynamo, and Microsoft Excel. Visual Basic was essential in creating the software model interface and codes in an easy-to-use graphical environment. Visual Basic was selected amongst other available software options like Xamarin, Bitbucket and Git primarily due to familiarity. Autodesk Revit was chosen amongst other design and visualization software due to its compatibility and easy integrability with third party programs. Also, Dynamo was chosen as the link because it is innately part of the Autodesk package and hence compatibility would be relatively easier.

3.2.4. The Artificial Intelligence Operation with Model Concepts

The model concepts are dependent on large data sets. The AI system conducts an iterative algorithm process and uses past results and patterns to inform future decisions. The loop created is self-learning and improves as the data set gets larger. The system implores a basic form of case-based reasoning (CBR). The model identifies location and climate parameters and with this, the system identifies sequences in the input data in order to draw comparisons.

For example, if a new location with a similar climate to Fargo-ND is selected, the system compares the necessary similarities and then suggests recommendations given by the Fargo field experts. The accuracy of recommendations depends on the inventory of data the system has hence expanding it in terms of construction practices and locations will improve its operation. **Figure 8** demonstrates the operation of the Case Based Reasoning (CBR) system in the model.

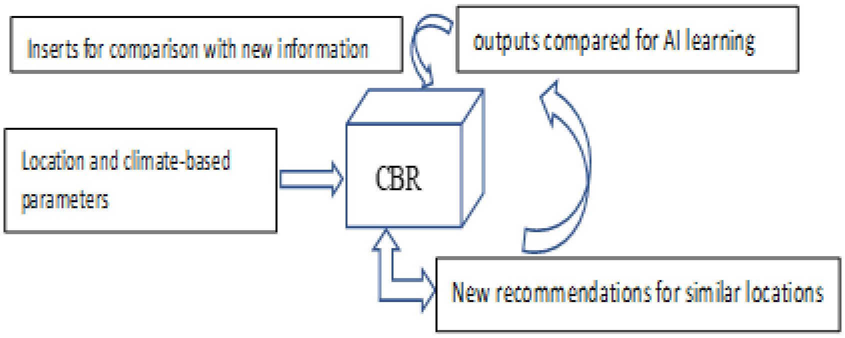


Figure 8. Illustration of Case Based reasoning of the AI system.

4. RESULTS AND DISCUSSION

4.1. Survey Results

The home owners were asked a range of questions including but not limited to basement type, use, problems encountered. As per survey results, majority (representing 50% of responses) admitted to owning finished-full basements with both unfinished-full and finished-partial basements coming in at 20% each and unfinished-partial basement with the minority share of 10%. This distribution is shown in **Figure 9.**

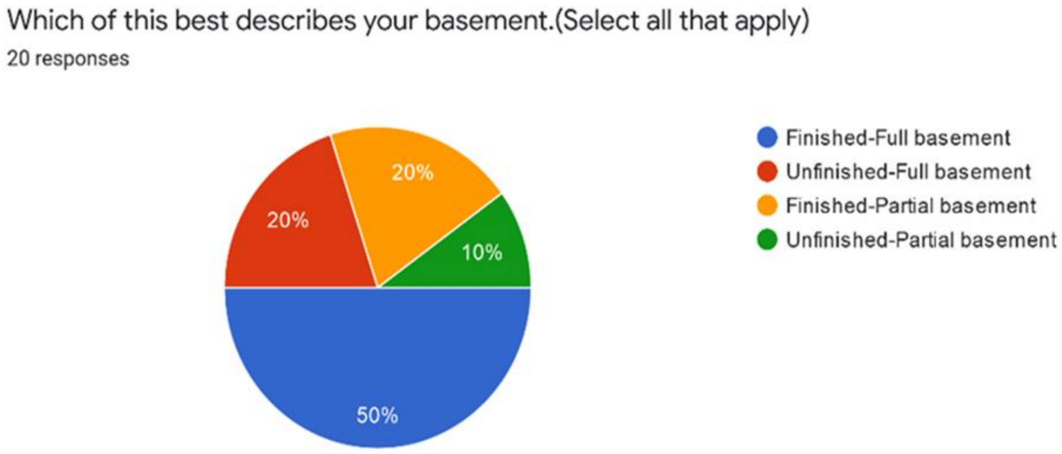


Figure 9. Home owner responses on basement type owned.

70% of respondents replied with having a basement depth of 8ft and this is in concurrence with the depths recommended by many local contractors for residential basements. The function of the basement was next in question with 60% of respondents using their basements as storage space as shown in **Figure 10**. Use as Utility/laundry room and office/study were the second most common use per the survey responses.

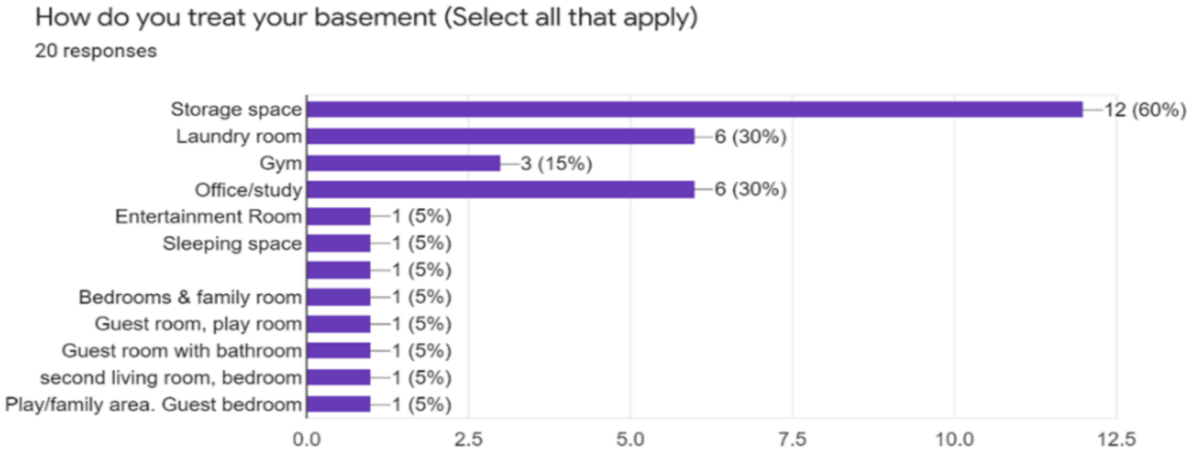


Figure 10. Home owner responses on basement usage.

One major information sought from the survey was the problems home owners faced with their basements. From the responses received, cracks in the walls and slab were common problems reported by home owners **(Figure 11)**. Equaling the number of respondents that reported the above issue was the problem with humidity and molds. Cracks and molds seem to be a common issue with basements according to past studies (Lstiburek 2019; Nguyen et al. 2020) conducted on basements and the survey only further affirmed this. Other issues including leaking/flooding and sinking basement floors were also reported. As stated earlier, these responses were essential in developing the interview questions for the local construction experts.

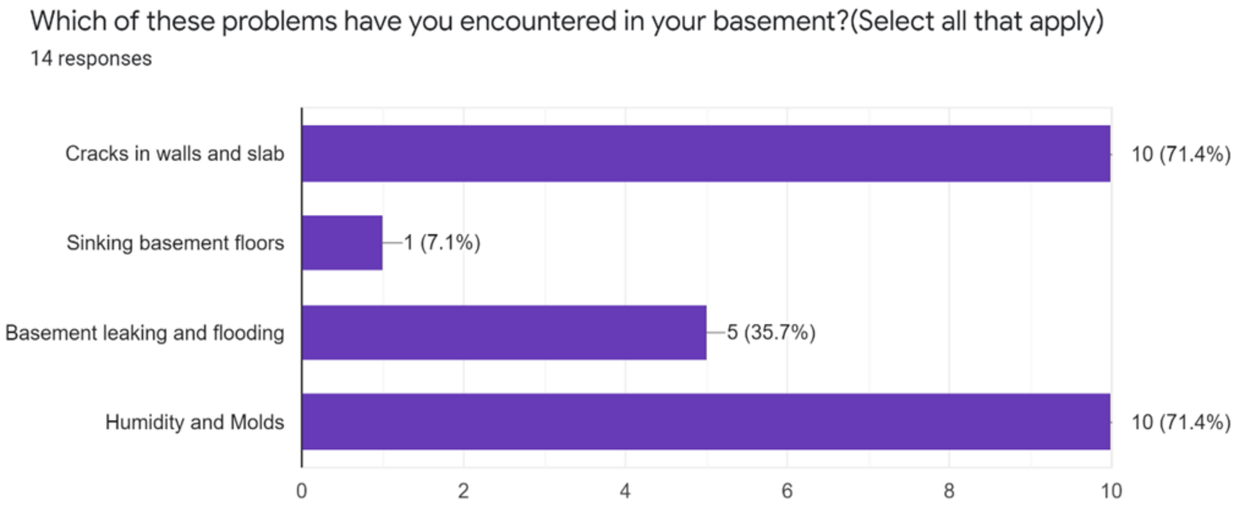


Figure 11. Home owner responses on problems encountered.

4.2. Human Expertise Collected from Local Construction Professionals

The surveys and interviews were crucial in collecting what is termed as human expertise in this study. The local contractors were interviewed in person to ascertain the best practices in basement construction. This is the core of this study as their responses were used in creating the database for the model to integrate human expertise with BIM. The interviews were also conducted to ascertain some clarity on the reasons to some of the issues reported as well as obtain opinions of the contractors on the best possible way to approach various construction processes in basement construction. The areas frequently discussed include excavation, concrete work, insulation, and safety. The subjects of drainage and ventilation were also touched on by some local contractors. During the interviews, the following issues were discussed with their associated effects and remedies.

4.2.1. Frost Heaving

The presence of frost in the soil can affect construction activities (Zhang et al.2019). In Fargo North-Dakota however, frost in the soil is not an uncommon phenomenon. With low temperatures, water between pore spaces freezes into ice and moves upward with increasing ground pressure. This phenomenon is termed as Frost heaving (Qin et al 2019). Frost heaving can therefore be defined as the upward swelling of soil caused by ice due to low freezing temperatures ((Huang et al 2018); (Qin et al 2019)). The movement of soils in this manner can displace objects within the ground including foundations. Movements of varying degrees of foundation structures can harm its structural integrity with resulting cracks developing to weaken the foundation structure and causing an eventual collapse in some cases. Local contractors mentioned this phenomenon as a possible cause of some occurrences of cracks in basements.

From the interviews, frost heaving protection can be summarized into two main ways namely: (1) Regulating ground temperatures to prevent frost formation, (2) Shielding foundation and basement structures from direct contact with frost. One remedy to guard against the effects of frost heaving is the extension of footings below the frostline. As per data from the national weather service, the average frost depth in Fargo ranges between 15 inches to 24 inches. It can however increase to as much as 3ft in the peak of winter. These depths must be taken into consideration when planning excavation activities. Another innovative method that was suggested was the use of sewer-pipes as sleeves for foundation columns. These sleeves prevent the frost from coming into direct contact with the columns to prevent heaving and movement of the columns during frosting and thawing. Frost formation can also be minimized by backfilling the areas around the columns and basement walls with crushed stone and gravel. The usual error made is backfilling with the same excavated material which is highly susceptible to waterlogging and frost development. The crushed stone and gravel backfill drains water away more efficiently from the structure.

4.2.1.1. The Case of Franchise Expansion

The study was expanded to ascertain feedback from contractors within a similar construction climate. Interviews with local contractors from Sioux Falls in South Dakota also revealed recommendations on frost depth footings like those given by contractors from Fargo. This supports studies that show construction practices and challenges across locations are similar primarily based on the dominant climatic conditions. (Apipattanavis et al, 2010), (Alshebani & Wedawatta (2014).

One contractor raised an interesting reason for why they usually have to amend building plans especially with the footings. It was stated that the issue is particularly prevalent when owners of franchises expand into the region. The owner's usually present building plans from their original locations with the assumption that this building template for their region would pass for other regions with minimal alterations.

4.2.2. Material Handling

Per contractor reports, material handling, including procurement, and storage, becomes a challenge under Fargo's extreme weather conditions. The extended periods of low temperatures affect the dynamics of material handling significantly. The usual procedures involved for storing different materials for example must be tweaked in order to preserve quality and intended longevity. Local contractors recommended that provisions be made for extra costs for material handling and use in Fargo's winter conditions. It was recommended to budget about 1.5 times the usual cost for construction materials. The increase in cost primarily has to do with the equipment such as hydronic heating systems required to regulate material temperatures.

Most of the local contractors recommended plastic sheath cladding as a cheaper alternative for regulating preserving concrete temperatures and shielding externally from snow and moisture. In addition, a contractor suggested that concrete should only be poured with the optimum temperature of between 50-60 degrees Fahrenheit. Also, all surfaces such as forms and rebars should be heated to a minimum of 35 degrees Fahrenheit before pouring of concrete. These ranges and values agree with specifications from the American Concrete Institute (ACI).

4.2.3. Insulation and Drainage

The natural drainage of Fargo is somewhat inconstant. The zone around the Red River of the North Valley has localized seasonal soil waterlogging (Kandel et al. 2013). Waterlogging is not a good situation for basements and foundation structures. Speaking on this, the local contractors mentioned that one must double down on the usual amount of insulation required for basements. They also suggested the use of French drains or drain tiles around the basement structure as this drain type has proven to be efficient in keeping water away from the basement. The combination of French drains and crushed rock backfill makes for excellent drainage ability of the underground structure.

For insulation materials, the common ones mentioned were fiber glass, spray foam and foam boards. They did not have a common preference for exterior insulation but stated that closed-cell spray foam is highly recommended for interior insulation due to its cost effectiveness and acceptable R-6 thermal resistance value.

4.2.4. Over-digging during Excavation

Over-digging can be described as excavating exceedingly more than the necessary required depth for the project foundation. The soil profile of a site usually exists in equilibrium and at natural compaction levels. Excavation inevitably disturbs this natural state hence the associated repercussions must be duly preempted. Some local contractors postulated over-digging as the potential cause of cracks in foundations. Over- digging disturbs far more soil than is required and optimum compaction cannot always be guaranteed.

When this happens, differential settlement of the soil is more likely to occur and cause cracks in the foundation. Caution must be taken during excavation to ensure the required excavation depth is not exceeded significantly. The required depths for excavation depend on numerous factors including the structural type/load, soil type etc. hence a range cannot be defined without proper investigation. The model hence gives a warning against over digging.

4.2.5. Scheduling Techniques

On the subject of scheduling, the local contractors recommended phased construction always when dealing with projects in Fargo outside the summer period. This is due to the extreme conditions presented by the weather during the winter periods. Activities like excavation and concrete pouring should go hand in hand. In other words, they recommended that concrete should be poured as soon as possible after excavation. In the actual words of one project supervisor he said, “With winter conditions like Fargo, we only excavate the amount you can pour that day, or immediately the next day. Do not dig any more than you can pour. This is mainly because you want to protect the bottom of the concrete footing and walls from frost. If you do not get it poured that night, cover the footings with blankets or use heating tubes to maintain adequate temperatures to keep the frost from getting under the footing.”

4.2.6. Safety in Basement Construction

This subject was discussed extensively with an OSHA representative. It was made known what inspectors look out for during inspection of construction sites with basement or general excavation activities. He mentioned that soils during excavation are classified into four groups based on their maximum allowable slope for excavation less than 20 feet. **Table 1** summarizes the soil types and their maximum allowable slopes. It was recommended that at least one visual and manual soil test should be conducted to determine the soil type before digging. In case of uncertainties, it is recommended to treat all soil types as type C (which is the least stable soil) type prior to obtaining clarification.

This means that the slope for digging should be at most 34 degrees. At this angle, employees are more likely protected from the caving in of the surrounding soil. Also, a ladder or ramp is required for access and egress at 4 feet. The ladder must always also be within twenty-five feet of lateral travel. This means that for every one hundred feet for example, an OSHA inspector expects to see at least two ladders in the excavated pit. He stressed that these are some simple things contractors can do to avoid unnecessary citations from inspectors during site visits.

Table 1. Soil Type and Recommended Excavation Slopes by OSHA Representative.

Soil or Rock Type	Maximum Allowable Slope for Excavation less than 20’
Stable Rock	Vertical (90 Deg.)
Type A	¾ to 1 (53 Deg.)
Type B	1 to 1 (45 Deg.)
Type C	1 ½ to 1 (34 Deg.)

The interviews with local construction experts revealed various adaptations they personally implement to mitigate certain location or process specific risks. The specifics within their recommendations will go a long way in reducing costs associated with change orders and/or repairs arising from mistakes or improper construction due to inadequate knowledge on a particular process. For example, the recommendations on material handling and drainage types can prevent many basement-related issues like cracking and flooding in the future. Far too often, home owners have to call for maintenance of these issues which could have been prevented with the implementation of the best practices.

Comparing the local expert recommendations with existing building codes shows a correlation between the recommended best practices and the City of Fargo's building code requirements as shown in **Table 2**. This improves the validity of the interview information.

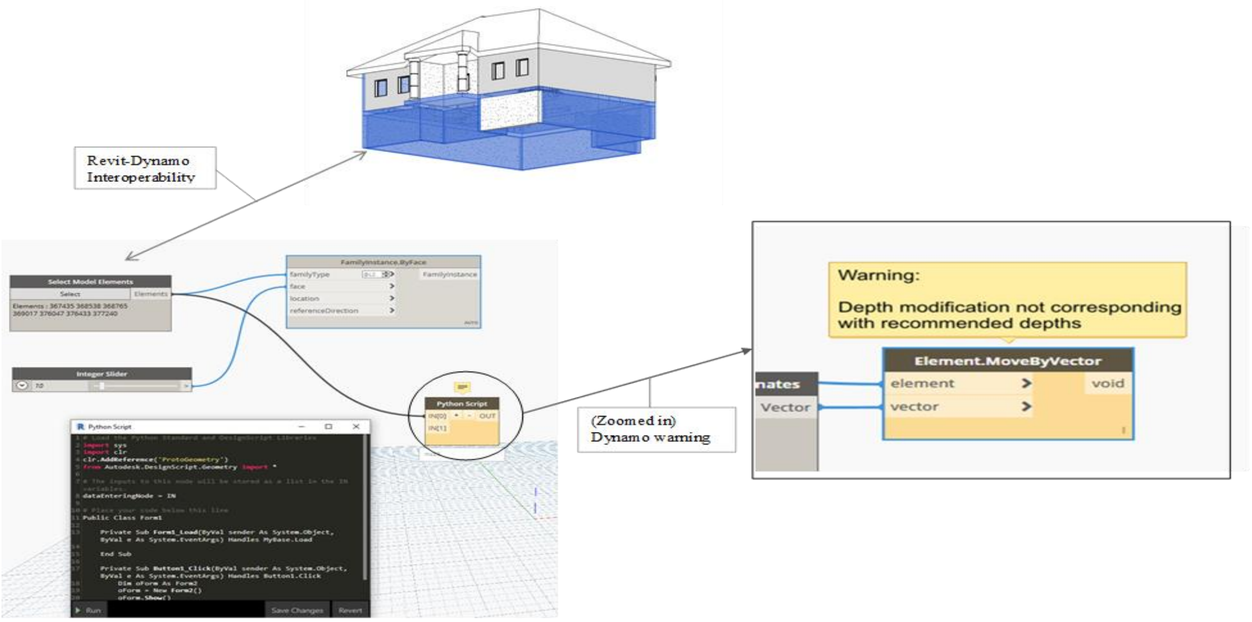
Table 2. Validation of Local Expert Recommendations with the City of Fargo Building Codes.

	Local Expert Recommendations	Quotes from the City of Fargo Building Inspections Department Handbook
Frost Depth	"One remedy to guard against the effects of frost heaving is to extend the footings below the frostline. As per data from the national weather service, the average frost depth in Fargo ranges between 15 inches to 24 inches	Regardless of whether your addition will be on a slab, like a garage, a full basement, or a crawl space, foundations are required to be on footings that are below frost depth. In the City of Fargo, this depth is 54 inches (four and a half feet). The minimum size depends on the material and the structure you will be building, including the type of foundation and number of stories. (City of Fargo Code and Permit Information – Cold Weather Concrete requirements. Retrieved from https://download .fargond.gov/0/cold_weather_concrete.pdf)
Material Handling	"Concrete should be poured at the optimum temperature range of 50 – 60 degrees Fahrenheit"	When "cold weather" conditions exist, concrete temperatures must be maintained at 50 degrees Fahrenheit for at least two days if using high early-strength or approved accelerated concrete. Three days of 50 degrees Fahrenheit concrete temperature is required for regular concrete. (City of Fargo Code and Permit Information – Cold Weather Concrete requirements. Retrieved from https://download .fargond.gov/0/cold_weather_concrete.pdf)
Safety	" Also, a ladder or ramp is required for access and egress at 4 feet. The ladder must always also be within 25 feet of lateral travel. This means that for every 100 feet for example, an OSHA inspector expects to see at least two ladders in the excavated pit."	OSHA requires employers to provide ladders, steps, ramps, or other safe means of egress for workers working in trench excavations 4 feet (1.22 meters) or deeper. The means of egress must be located so as not to require workers to travel more than 25 feet (7.62 meters) laterally within the trench. (Trenching and Excavation Safety OSHA Handbook)

The importance of human expertise in the construction process cannot be understated and hence efforts to integrate it with available software should be encouraged in order to realize the combined efficiency of computing and human decision making.

4.3. Developed Model Operations

Both model concepts have their respective pros and cons and can excel in varying scenarios. The Revit®- Dynamo model for example is one that directly shows warnings and recommendations while working on the design elements and decisions. With the individual elements of the Revit® model (i.e., walls, roof, windows etc.) linked with their respective nodes in Dynamo, Dynamo responds to changes made in Revit® by displaying the associated warnings and recommendations. For the instance in **Figure 12**, a basement depth of 3ft was selected in Revit®. The Dynamo warning “Depth modification not corresponding with recommended depth” was immediately triggered since the model depth selected did not align with the specified depth range coded into the model with the python script. A safe depth range of 5ft to 8ft was recommended by construction experts to guard against the effects of frost heaving since any lesser depth will fall in the ice plain in Fargo peak winter. The model displays recommendations once the user selects a depth that is not in agreement with the field expert recommendations.



Python Script

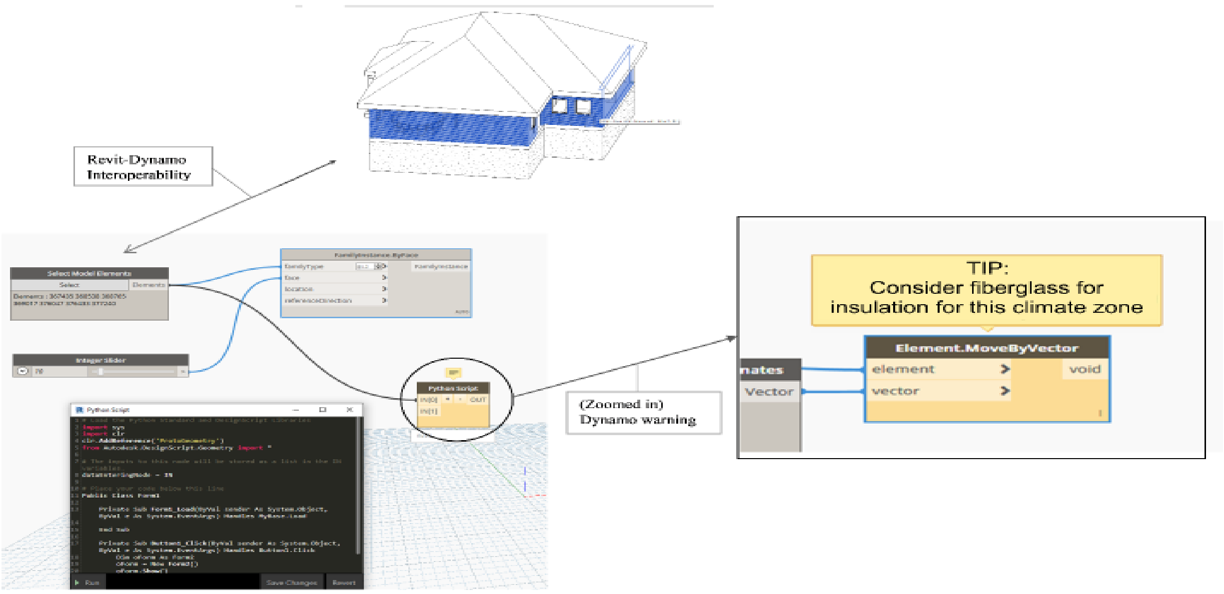
```
# Load the Python Standard and DesignScript Libraries
import sys
import clr
clr.AddReference('ProtoGeometry')
from Autodesk.DesignScript.Geometry import *

# The inputs to this node will be stored as a list in the IN
variables.
dataEnteringNode = IN

# Place your code below this line
Public Class Form1

    Private Sub Form1_Load(ByVal sender As System.Object,
    ByVal e As System.EventArgs) Handles MyBase.Load

    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object,
    ByVal e As System.EventArgs) Handles Button1.Click
        Dim oForm As Form2
        oForm = New Form2()
        oForm.Show()
```

Warning:

Depth modification not corresponding with recommended depths

Figure 12. Schematic view of Revit-Dynamo workflow project warning.

The Revit-Dynamo model operates in this manner by displaying related recommendations or warnings for the user to consider in decision making. With this concept, human expertise has been primarily integrated and relayed with BIM software. The Visual Basic model on the other hand can operate as a standalone interface. This model works on information stored in a database. Unlike the Revit®-Dynamo model, the VB model provides the warnings and recommendations in the form of a list. This model is best for cross-checking design parameters occasionally since it does not offer warnings in real-time. For further testing and to explore the versatility of the model, recommendations giving by local experts on thermal insulation was coded into the model. The wall elements from the Revit®-Dynamo model were activated and the users receive information on recommended suitable insulation materials based on the suggestions of local contractors as shown in **Figure 13**. As shown in this example with insulation, the Revit-Dynamo model promises simple expandability with the introduction of new information from the various divisions contained in the construction specifications institute (CSI) format.



TIP:
Consider fiberglass for insulation for this climate zone

Figure 13. Model displaying suggestions on insulation material.

4.3.1. Challenges and Limitations of Study

This study had some hurdles that needed to be overcome. Getting respondents to both home owner and contractor surveys data collection process was challenging as people are naturally reluctant in sharing information. This is evident in the resulting respective sample sizes. The interviews with local field experts also required extensive planning and occasional rescheduling due to unaligned individual availabilities. The model concepts have their respective limitations that can be addressed with further development. The Revit-Dynamo concept requires an amount of software shrewdness in order to operate. This is admittedly due to the slightly complex interoperability interface. This interface can be simplified with future developments.

The Visual basic concept ,as stated earlier, provides recommendations in a list form. This form is relatively less interactive compared to the Revit-Dynamo concept where the recommendations are shown as suggestion and warning pop-ups. Both concepts require basic computing knowledge to navigate their respective interfaces. This may be challenging for people with limited computing literacy. Mobile app versions can be developed to enhance the versatility and accessibility of both model concepts.

5. CONCLUSION

With the utmost goal of human expertise integration, this study examined feasible ways of integrating this valuable form of data in construction with available BIM software. This study revealed many recommendations from local experts on a specific construction issue and location. This raises the question about how much information is out there embedded in the minds of these experts that can be used with available technology to improve human-AI collaboration. Clearly, the field experts in Fargo had good advice and warnings on basement construction. There is a strong indication from this study that other building processes in other locations will have their own unique issues and recommendations. The models developed are a step in the right direction in that, it illustrates a preliminary and basic form of human-BIM integration. This study has immense potential as it can bridge a longstanding gap in the construction industry in terms of human and computer cooperation.

Future studies can develop a database of best practices for different building processes in other locations. The collection of human expertise from diverse locations and different building processes is an essential step for the creation of a complex adaptive system in construction and pushing the human-AI collaboration agenda. This is because, the more information we have available speeds up the machine learning process and in effect predisposes available technologies to be of more help to humans in construction. Since construction is an industry that requires heavy communication and collaboration, the integration of human expertise with BIM can significantly improve the workflow and mitigate potential information and communication-based conflicts.

6. REFERENCES

Abbasi, O., Noorzai, E., Gharouni Jafari, K., & Golabchi, M. (2020). Exploring the causes of delays in construction industry using a cause-and-effect diagram: case study for Iran. Journal of Architectural Engineering, 26(3), 05020008.

Ahiable, C., & Banawi, A. A. (2021, July). Progression of Human Expertise Integration in the Construction Industry. In International Conference on Applied Human Factors and Ergonomics (pp. 45-50). Springer, Cham.

Andrić, J. M., Mahamadu, A. M., Wang, J., Zou, P. X., & Zhong, R. (2019). The cost performance and causes of overruns in infrastructure development projects in Asia. Journal of Civil Engineering and Management, 25(3), 203-214.

Alagidede, P., & Mensah, J. O. (2018). Construction institutions and economic growth in sub-Saharan Africa. African Review of Economics and Finance, 10(1), 136-163.

Alshebani, M. N., & Wedawatta, G. (2014). Making the construction industry resilient to extreme weather: lessons from construction in hot weather conditions. Procedia Economics and Finance, 18, 635-642.

Alone, M. S. S. D. (2020). Clash Detection and Elimination using BIM. International Research Journal of Engineering and Technology, 07, 6231- 6236.

Alkass, S., Mazerolle, M. and Harris, F. (1996) Construction delay analysis techniques. Construction Management and Economics, 14, 375–94.

Apipattanavis, S., Sabol, K., Molenaar, K. R., Rajagopalan, B., Xi, Y., Blackard, B., & Patil, S. (2010). Integrated framework for quantifying and predicting weather-related highway construction delays. Journal of construction engineering and management, 136(11), 1160-1168.

Arciszewski, T., and Rossman, L. (eds.) (1992). Knowledge acquisition in civil engineering, ASCE, New York, N.Y.

Arditi, D. and Gunaydin, H.M., 1997. Total quality management in the construction process. International Journal of Project Management, 15(4), pp.235-243.

Asl, M. R., Zarrinmehr, S., Bergin, M., & Yan, W. (2015). BPOpt: A framework for BIM-based performance optimization. Energy and Buildings, 108, 401-412.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), 241-252.

Azhar, S., Khalfan, M., & Maqsood, T. (2015). Building information modelling (BIM): now and beyond. Construction Economics and Building, 12(4), 15-28. https://doi.org/10.5130/AJCEB.v12i4.3032

Banawi, A. A., Ahiable, C., Gao, Z., & Bin, B. (2020). Identifying Best Practices for the Construction of Residential Basements in Fargo, North Dakota, USA Using Building Information Modeling (BIM). In International Conference on Applied Human Factors and Ergonomics (pp. 161-167). Springer, Cham.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. Automation in construction, 59, 113-121.

Borgheipour, H., Tehrani, G., Madadi, S., & Mohammadfam, I. (2020). Identification and assessment of human errors among tower crane operators using SHERPA and CREAM techniques. Journal of Health and Safety at Work, 10(1), 5-8.

Cox III, R.W., Hill, M.L. and Pyakuryal, S., (2008). Tacit knowledge and discretionary judgment. Public Integrity, 10(2), pp.151-164.

Chan, A., Yung, E., Lam, P., Tam, C. and Cheung, S. (2001) Application of Delphi method in selection of procurement systems for construction projects. Construction Management and Economics, 19, 699–718.

Ching, F. D. (2020). Building construction illustrated. John Wiley & Sons.

Dixit, S., Mandal, S. N., Thanikal, J. V., & Saurabh, K. (2019). Evolution of studies in construction productivity: A systematic literature review (2006–2017). Ain Shams Engineering Journal, 10(3), 555-564.

Dixon, S.R., C.D. Wickens, and D. Chang. (2005). "Mission Control of Multiple Unmanned Aerial Vehicles: A Workload Analysis." Human Factors 47 (3): 479–487. doi:10.1518/001872005774860005.

Dreyfus, H. and Dreyfus, S. (2005) Expertise in real world contexts. Organi-zation Studies, 26(5), 779–92.

Eastman, C. M., Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors. John Wiley & Sons.

El-Sayegh, S. M., & Mansour, M. H. (2015). Risk assessment and allocation in highway construction projects in the UAE. Journal of Management in Engineering, 31(6), 04015004.

Erdal, H. (2015). Contribution of machine learning methods to the construction industry: Prediction of compressive strength. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 21(3), 109-114

Eyal, G. (2013). For a sociology of expertise: The social origins of the autism epidemic. American Journal of Sociology, 118(4), 863-907.

Farmer, M. (2016). Modernize or die. London, Construction Leadership Council.

Farnsworth, C. B., Beveridge, S., Miller, K. R., & Christofferson, J. P. (2015). Application, advantages, and methods 43associated with using BIM in commercial construction. International Journal of Construction Education and Research, 11(3), 218-236.

Feigenbaum, E. (1992) A Personal View of Expert Systems: Looking Back and Looking Ahead, Report No. KSL 92-41, Knowledge Systems Laboratory, Stanford University, Stanford, CA, available at https://goo.gl/Nk5Xgc (accessed 28 August 2015).

Friedson, E. (2001) Professionalism: The Third Logic, PolityPress, Cambridge.

Flanagan, R., Kendell, A., Norman, G., & Robinson, G. D. (1987). Life cycle costing and risk management. Construction Management and Economics, 5(4), S53-S71.

Gamil, Y., & Rahman, I. A. (2017). Identification of causes and effects of poor communication in construction industry: A theoretical review. Emerging Science Journal, 1(4), 239-247.

Gao, F., Zhou, H., Liang, H., Weng, S., & Zhu, H. (2020). Structural deformation monitoring and numerical simulation of a supertall building during construction stage. Engineering Structures, 209, 110033.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K. (2017). Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks, and challenges. Renewable and Sustainable Energy Reviews, 75, 1046-1053.

Ghassemi, R. and Becerik-Gerber, B., (2011). Transitioning to Integrated Project Delivery: Potential barriers and lessons learned. Lean construction journal.

Glick, S., and Guggemos, A. (2009). “IPD and BIM: Benefits and opportunities for regulatory agencies.” Proc., 45th Associated Schools of Construction National Conference, Gainesville, FL.

Hamza, M., Shahid, S., Bin Hainin, M. R., & Nashwan, M. S. (2019). Construction labour productivity: review of factors identified. International Journal of Construction Management, 1-13.

Huang, S., Liu, Q., Liu, Y., Kang, Y., Cheng, A., & Ye, Z. (2018). Frost heaving and frost cracking of elliptical cavities (fractures) in low-permeability rock. Engineering Geology, 234, 1-10.

Inui, T., Chau, C., Soga, K., Nicolson, D., & O’Riordan, N. (2011). Embodied energy and gas emissions of retaining wall structures. Journal of Geotechnical and Geoenvironmental Engineering, 137(10), 958-967.

Jaeger, M, and D Adair. “Human Factors Simulation in Construction Management Education.” European Journal of Engineering Education 35.3 (2010): 299–309. Web.

Jaillon, L., & Poon, C. S. (2008). Sustainable construction aspects of using prefabrication in dense urban environment: a Hong Kong case study. Construction management and Economics, 26(9), 953-966.

Juran, J. M. (1988), Juran's Quality Control Handbook, (4th ed.). McGraw-Hill:New York.

Kadry, M., Osman, H., & Georgy, M. (2017). Causes of construction delays in countries with high geopolitical risks. Journal of construction engineering and management, 143(2), 04016095.

Kandel, H. J., Brodshaug, J. A., Steele, D. D., Ransom, J. K., DeSutter, T. M., & Sands, G. R. (2013). Subsurface drainage effects on soil penetration resistance and water table depth on a clay soil in the Red River of the North Valley, USA. Agricultural Engineering International: CIGR Journal, 15(1), 1-10.

Kandregula, S. K. (2020). Investigating the Perceived Human Errors in 4D-BIM Construction Scheduling.

Koscheyev, V., Rapgof, V., & Vinogradova, V. (2019). Digital transformation of construction organizations. In IOP Conference Series: Materials Science and Engineering (Vol. 497, No. 1, p. 012010). IOP Publishing.

KPMG. (2015). The 2015 Global Construction Project Owners Survey. United States: KPMG.

Livingston, C. (2008). From CAD to BIM: Constructing opportunities in architectural education. In AEI 2008: Building Integration Solutions (pp. 1-9).

Lstiburek, J. W. (2019). Keeping the Water Out of Basements. ASHRAE Journal, 61(3), 62-68.

Masood, R., Kharal, M. K. N., & Nasir, A. R. (2014). Is BIM adoption advantageous for construction industry of Pakistan. Procedia Engineering, 77, 229-238.

Mcbride, Sara E, Wendy A Rogers, and Arthur D Fisk. (2014). “Understanding Human Management of Automation Errors.” Theoretical Issues in Ergonomics Science 15.6:545–577. Web.

Moray, N., T. Inagaki, and M. Itoh. (2000). “Adaptive Automation, Trust, and Self-Confidence in Fault Management of Time-Critical Tasks.” Journal of Experimental Psychology-Applied 6 (1): 44–58. doi:10.1037//0278-7393.6.1.44.

Morton, P. J., & Thompson, E. M. (2011). Uptake of BIM and IPD within the UK AEC Industry: the evolving role of the architectural technologist. Built and Natural Environment Research Papers, 4(2), 275-286.

Nguyen, S. H., Do, T. T., & Ambre, J. (2020). Study on INTOC Waterproofing Technology for Basement of High- Rise Buildings. In 2020 5th International Conference on Green Technology and Sustainable Development (GTSD) (pp. 516-522). IEEE.

Ning, X., Lam, K.C. and Lam, M.C.K., 2011. A decision-making system for construction site layout planning. Automation in construction, 20(4), pp.459-473.

Okoroh, M. and Torrance, V. (1999) A model for subcontractor selection in construction projects. Construction Management and Economics, 17, 315–27.

Olawumi, T. O., Chan, D. W., & Wong, J. K. (2017). Evolution in the intellectual structure of BIM research: A bibliometric analysis. Journal of Civil Engineering and Management, 23(8), 1060-1081.

Pagano, T. C., Pappenberger, F., Wood, A. W., Ramos, M. H., Persson, A., & Anderson, B. (2016). Automation and human expertise in operational river forecasting. Wiley Interdisciplinary Reviews: Water, 3(5), 692-705.

Pan, Y., & Zhang, L. (2021). Roles of artificial intelligence in construction engineering and management: A critical review and future trends. Automation in Construction, 122, 103517.

Parasuraman, R., T.B. Sheridan, and C.D. Wickens. (2000). “A Model for Types and Levels of Human Interaction with Automation.” IEEE Transactions on Systems Man and Cybernetics Part A-Systems and Humans 30 (3): 286–297.

Pradier, M. F., Zazo, J., Parbhoo, S., Perlis, R. H., Zazzi, M., & Doshi-Velez, F. (2021). Preferential Mixture-of- Experts: Interpretable Models that Rely on Human Expertise As Much As Possible. arXiv preprint arXiv:2101.05360.

Pyke, C., McMahon, S., Dietsche, T., & Council, U. G. B. (2010). Green building & human Expertise. USGBC research program white paper.

Qin, Z., Lai, Y., Tian, Y., & Yu, F. (2019). Frost-heaving mechanical model for concrete face slabs of earthen dams in cold regions. Cold Regions Science and Technology, 161, 91-98.

Sage, D. J. (2016). Rethinking construction expertise with posthumanism. Construction management and economics, 34(7-8), 446-457.

Shaikh S. (2017).Labor: Meaning, Kinds and Importance | Economics. Retrieved from http://www.economicsdiscussion.net/labour/labour-meaning-kinds-and-importance-economics/13749

Sohn-Rethel, A. (2020). Intellectual and manual labour: A critique of epistemology. Brill.

Swain, A., Guttman, H. 1983. Handbook of Human Reliability Analysis with Emphasis on Nuclear Poser Plan Applications: Final Report (NUREG/CR-1278). United States Nuclear Regulatory Commission, Washington, DC.

Tan, Y. C., & Chow, C. M. (2008). Design of retaining wall and support systems for deep basement construction–a Malaysian Expertise. In Seminar on “Deep Excavation and Retaining Walls”, Jointly organized by IEM-HKIE, Malaysia (Vol. 24).

Thurairajah, N., & Goucher, D. (2013). Advantages and challenges of using BIM: A cost consultant’s perspective.

Tornincasa, S., & Di Monaco, F. (2010). The future and the evolution of CAD. In Proceedings of the 14th international research/expert conference: trends in the development of machinery and associated technology (Vol. 1, No. 1, pp. 11-18).

Trevor, (2019, May 31). Mental Labor vs. Physical Labor. Retrieved from https://www.canyon-news.com/mental-labor-vs-physical-labor/92890

Tixier, A. J. P., Hallowell, M. R., Rajagopalan, B., & Bowman, D. (2016). Application of machine learning to construction injury prediction. Automation in construction, 69, 102-114.

T. W. Liao, P. J. Egbelu, B. R. Sarker, and S. S. Leu, (2011). “Metaheuristics for project and construction management—a state-of-the-art review,” Automation in Construction, vol. 20, no. 5, pp. 491–505.

Tornincasa, S., & Di Monaco, F. (2010, September). The future and the evolution of CAD. In Proceedings of the 14th international research/expert conference: trends in the development of machinery and associated technology (Vol. 1, No. 1, pp. 11-18).

Tylek, I., Kuchta, K., & Rawska-Skotniczny, A. (2017). Human errors in the design and execution of steel structures— a case study. Structural Engineering International, 27(3), 370-379.

Wang, H., Nokia Oyj, (2009). Apparatus, method, and computer program product for providing an input gesture indicator. U.S. Patent Application 12/057,863

Yu, K. H., & Hui, E. C. M. (2018). Housing construction and uncertainties in a high-rise city. Habitat International, 78, 51-67.

Zastrow, P., Molina-Moreno, F., García-Segura, T., Martí, J. V., & Yepes, V. (2017). Life cycle assessment of cost-optimized buttress earth-retaining walls: A parametric study. Journal of Cleaner Production, 140, 1037-1048.

Zhang, G., Yu, H., Li, H., & Yang, Y. (2019). Experimental study of deformation of early age concrete suffering from frost damage. Construction and Building Materials, 215, 410-421

APPENDIX A. CODE FOR VISUAL BASIC MODEL INTERFACE ONLY

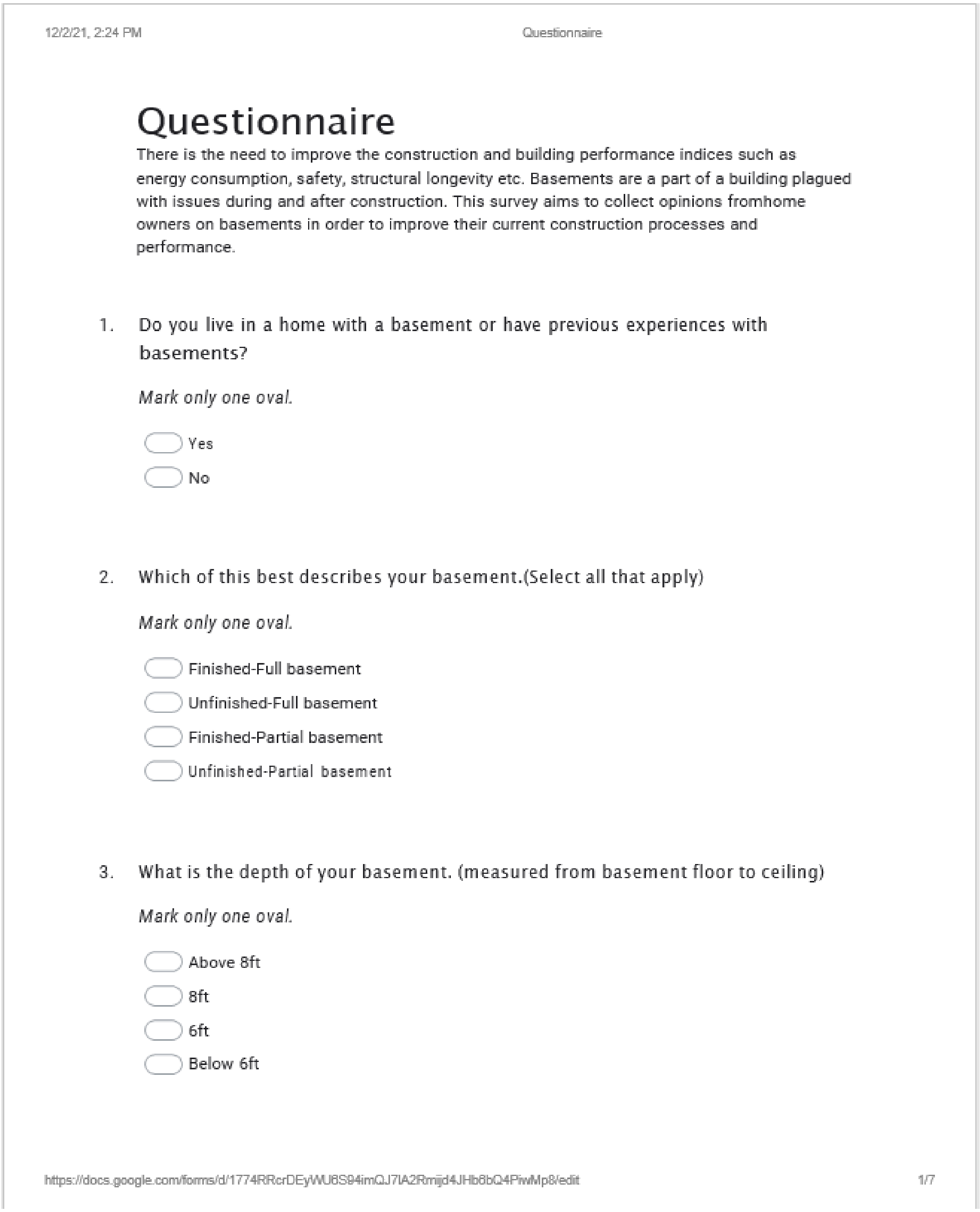
```
Public Class Form1

    Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles MyBase.Load

    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button1.Click
        Dim oForm As Form2
        oForm = New Form2()
        oForm.Show()
        oForm = Nothing
    End Sub

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button2.Click
        MonthCalendar1.SetDate(TextBox1.Text)
    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button3.Click
        If ListBox1.Visible = True Then
            ListBox1.Visible = False
        Else
            ListBox1.Visible = True
        End If
    End Sub

    Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button4.Click
        If ListBox2.Visible = True Then
            ListBox2.Visible = False
        Else
            ListBox2.Visible = True
        End If
    End Sub

    Private Sub Button5_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button5.Click
        If ListBox3.Visible = True Then
            ListBox3.Visible = False
        Else
            ListBox3.Visible = True
        End If
    End Sub
End Class
```

APPENDIX B. INTERVIEW / SURVEY QUESTIONS AND SURVEY RESULTS

B.1. Interview Questions

1. What is your role on this project site?
2. How many years of experience do you have in the construction industry?
3. What has been your path within the industry in terms of projects, locations, and roles?
4. How many construction projects have you been involved in the Fargo-North Dakota Area?
5. What are some challenges specific to construction in this area?
6. Can you speak on basement construction in Fargo and challenges you have faced?
7. What are some practices you personally apply to overcome these challenges?
8. Do you think these practices are common knowledge?
9. What do you think of an avenue (model or database) to store this knowledge you just sharedto be made available to everyone interested?
10. Do you think these tips will be useful? and if yes, in what way?

B.2. Home Owner Survey Questions



12/2/21, 2:24 PM Questionnaire

Questionnaire

There is the need to improve the construction and building performance indices such as energy consumption, safety, structural longevity etc. Basements are a part of a building plagued with issues during and after construction. This survey aims to collect opinions fromhome owners on basements in order to improve their current construction processes and performance.

1. Do you live in a home with a basement or have previous experiences with basements?

Mark only one oval.

○ Yes
○ No

2. Which of this best describes your basement.(Select all that apply)

Mark only one oval.

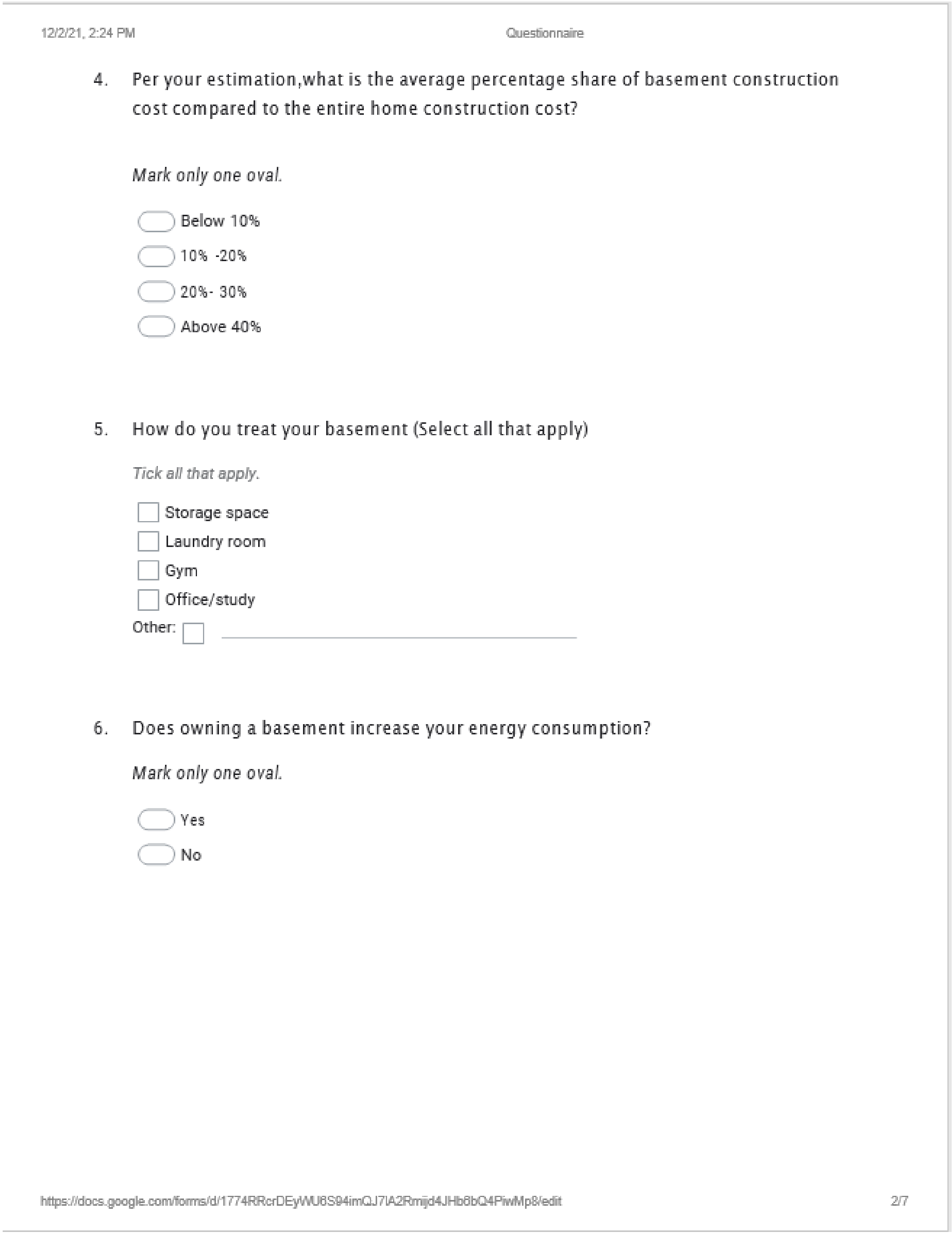
○ Finished-Full basement
○ Unfinished-Full basement
○ Finished-Partial basement
○ Unfinished-Partial basement

3. What is the depth of your basement. (measured from basement floor to ceiling)

Mark only one oval.

○ Above 8ft
○ 8ft
○ 6ft
○ Below 6ft

https://docs.google.com/forms/d/1774RRcrDEyWU6S94imQJ7lA2Rmijd4JHb6bQ4PiwMp8/edit 1/7



12/2/21, 2:24 PM Questionnaire

4. Per your estimation,what is the average percentage share of basement construction cost compared to the entire home construction cost?

Mark only one oval.

○ Below 10%
○ 10% -20%
○ 20%- 30%
○ Above 40%

5. How do you treat your basement (Select all that apply)

Tick all that apply.

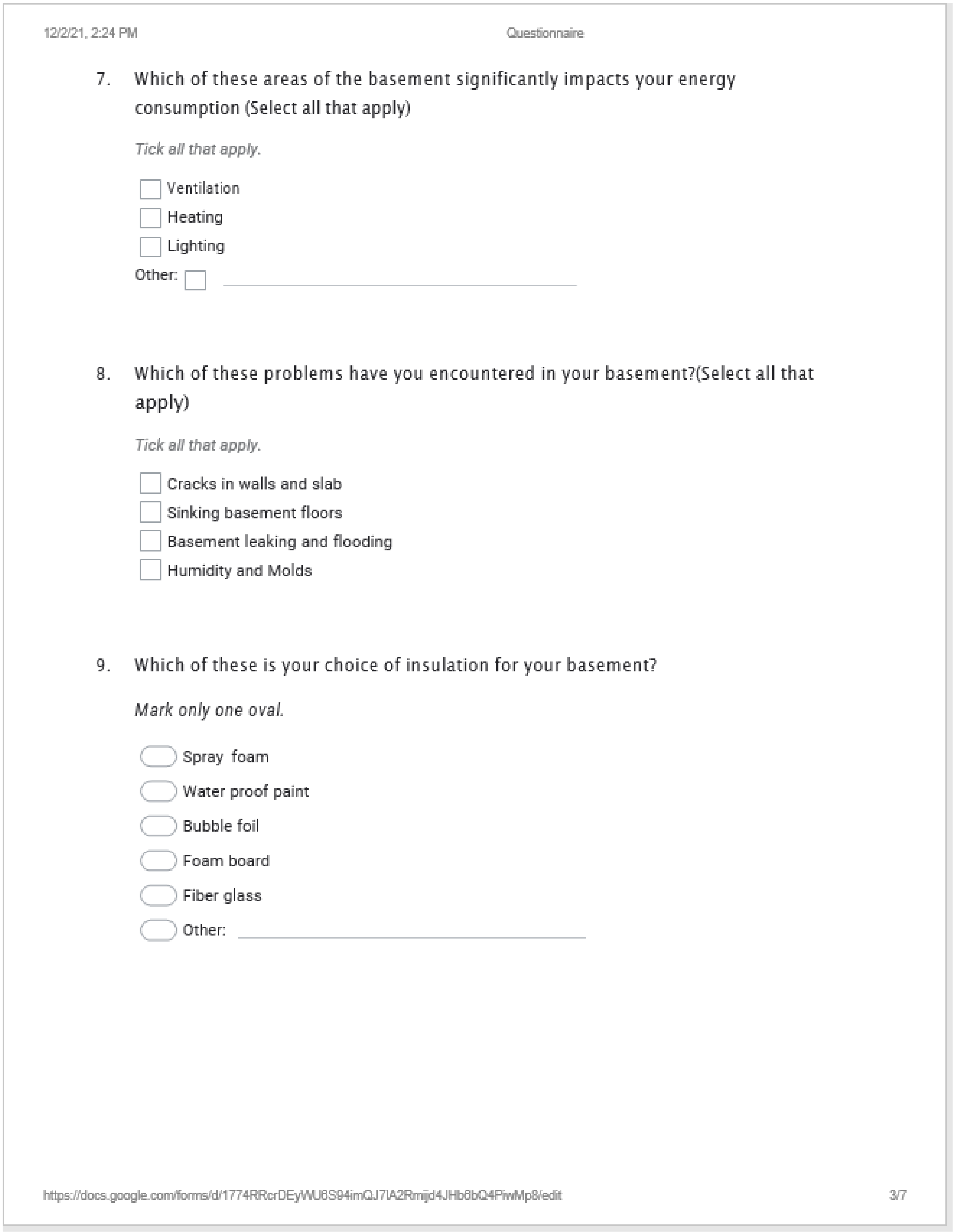
☐ Storage space
☐ Laundry room
☐ Gym
☐ Office/study
Other: ☐ ____________________

6. Does owning a basement increase your energy consumption?

Mark only one oval.

○ Yes
○ No

https://docs.google.com/forms/d/1774RRcrDEyWU6S94imQJ7lA2Rmijd4JHb6bQ4PiwMp8/edit 2/7



12/2/21, 2:24 PM Questionnaire

7. Which of these areas of the basement significantly impacts your energy consumption (Select all that apply)

Tick all that apply.

☐ Ventilation
☐ Heating
☐ Lighting
Other: ☐ ____________________

8. Which of these problems have you encountered in your basement?(Select all that apply)

Tick all that apply.

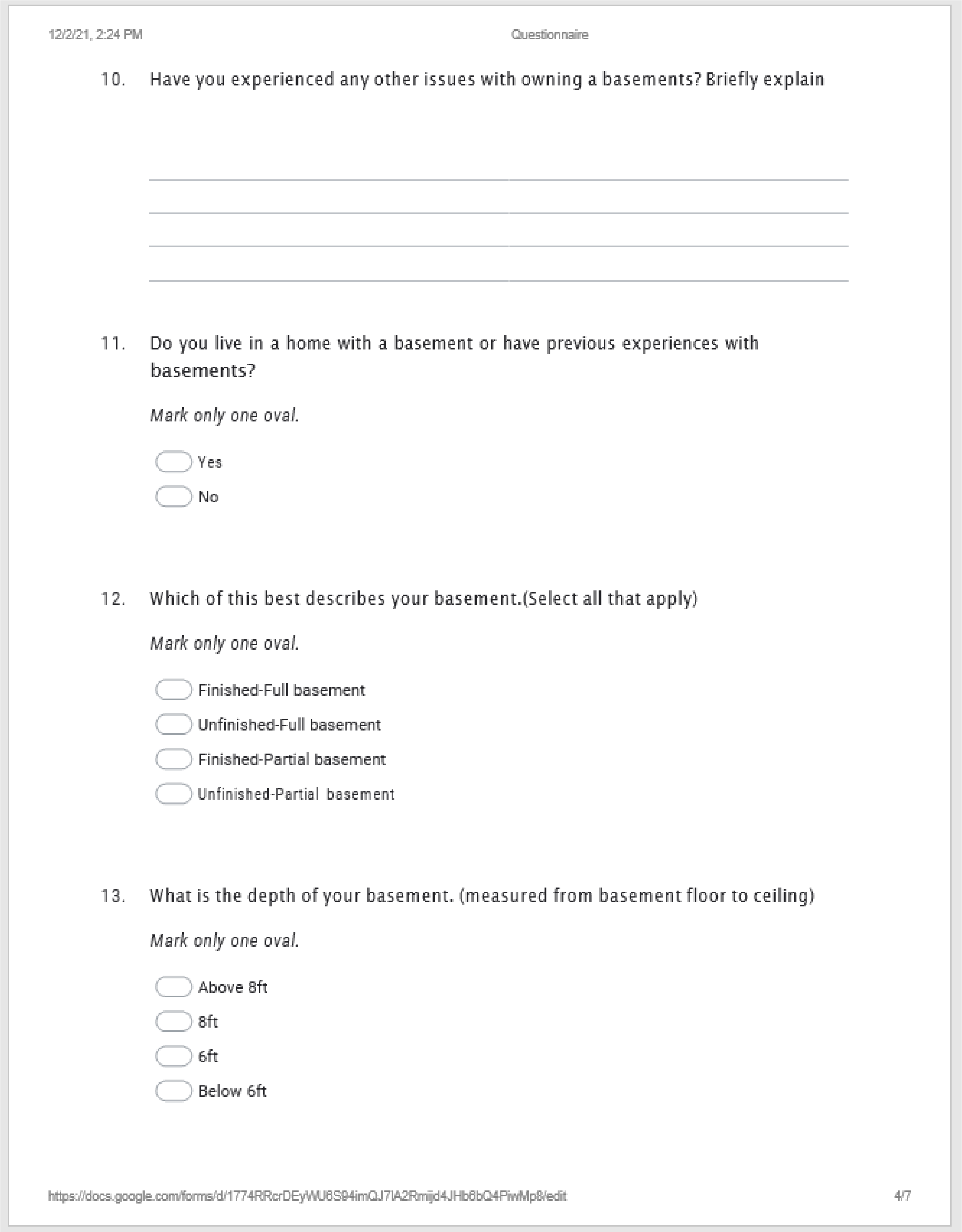
☐ Cracks in walls and slab
☐ Sinking basement floors
☐ Basement leaking and flooding
☐ Humidity and Molds

9. Which of these is your choice of insulation for your basement?

Mark only one oval.

○ Spray foam
○ Water proof paint
○ Bubble foil
○ Foam board
○ Fiber glass
○ Other: ____________________

https://docs.google.com/forms/d/1774RRcrDEyWU6S94imQJ7lA2Rmijd4JHb6bQ4PiwMp8/edit 3/7



12/2/21, 2:24 PM Questionnaire

10. Have you experienced any other issues with owning a basements? Briefly explain

11. Do you live in a home with a basement or have previous experiences with basements?

Mark only one oval.

○ Yes
○ No

12. Which of this best describes your basement.(Select all that apply)

Mark only one oval.

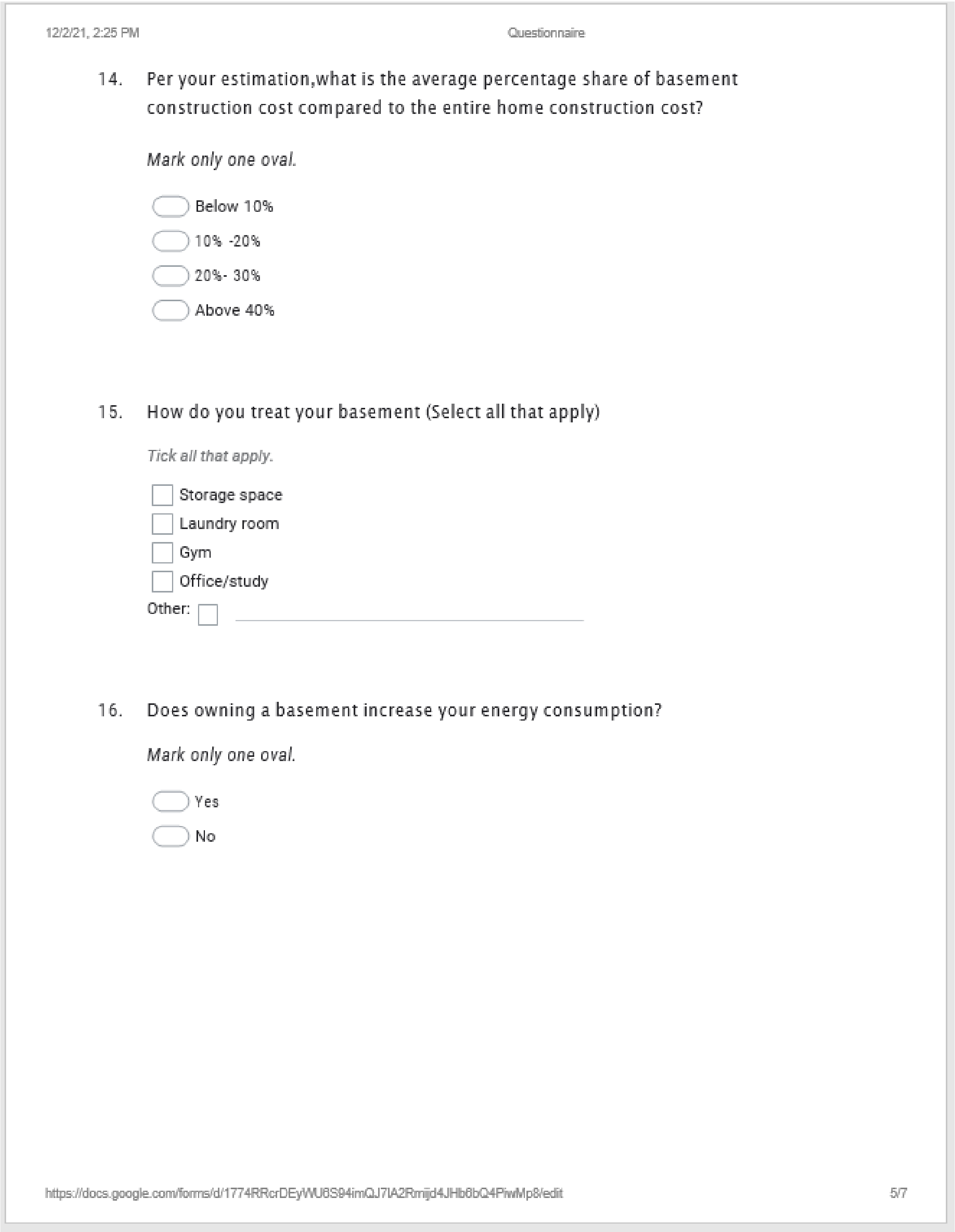
○ Finished-Full basement
○ Unfinished-Full basement
○ Finished-Partial basement
○ Unfinished-Partial basement

13. What is the depth of your basement. (measured from basement floor to ceiling)

Mark only one oval.

○ Above 8ft
○ 8ft
○ 6ft
○ Below 6ft

https://docs.google.com/forms/d/1774RRcrDEyWU6S94imQJ7lA2Rmijd4JHb6bQ4PiwMp8/edit 4/7



12/2/21, 2:25 PM Questionnaire

14. Per your estimation,what is the average percentage share of basement construction cost compared to the entire home construction cost?

Mark only one oval.

○ Below 10%
○ 10% -20%
○ 20%- 30%
○ Above 40%

15. How do you treat your basement (Select all that apply)

Tick all that apply.

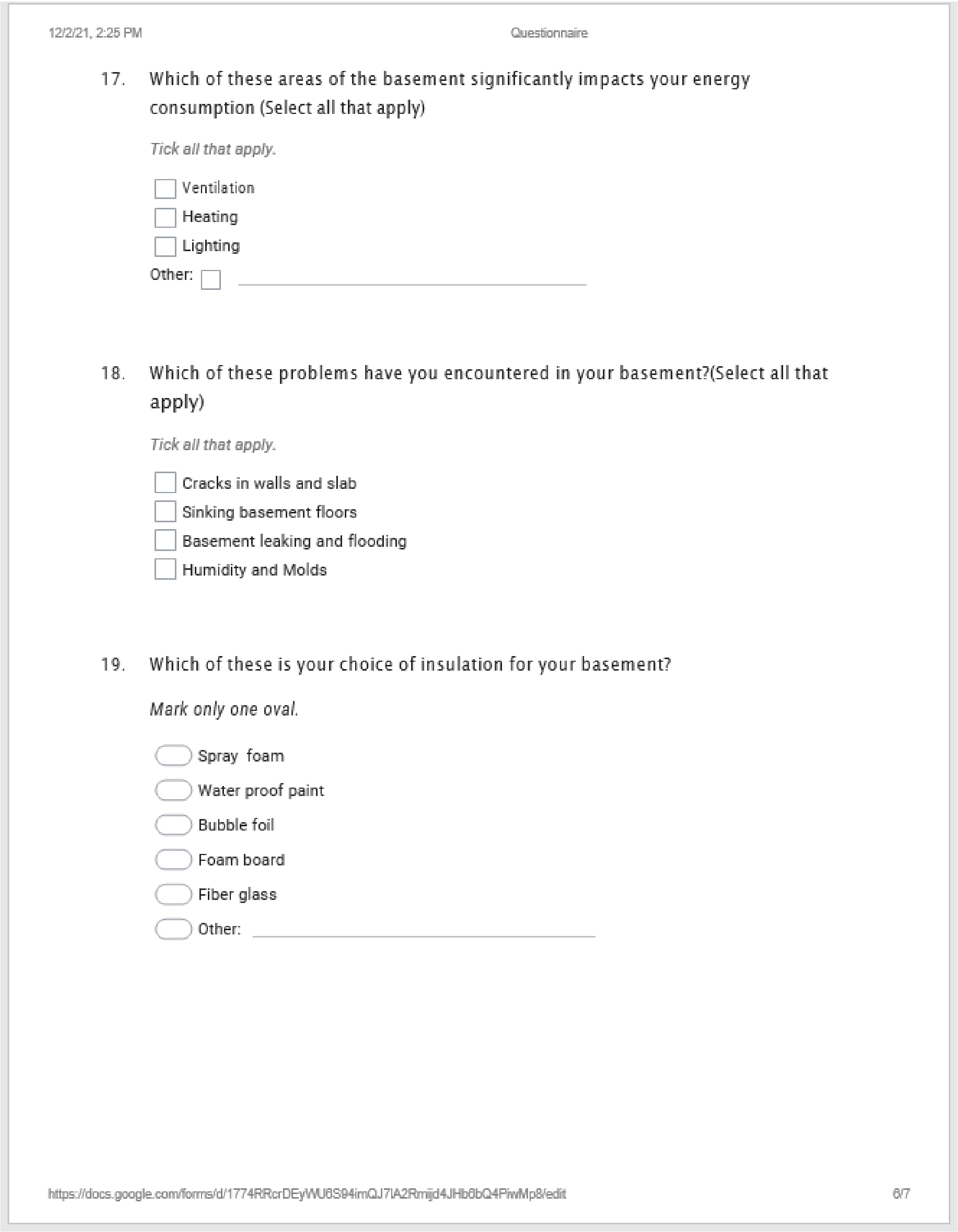
☐ Storage space
☐ Laundry room
☐ Gym
☐ Office/study
Other: ☐ ______________

16. Does owning a basement increase your energy consumption?

Mark only one oval.

○ Yes
○ No

https://docs.google.com/forms/d/1774RRcrDEyWU8S94imQJ7lA2Rmijd4JHb6bQ4PiwMp8/edit 5/7



12/2/21, 2:25 PM Questionnaire

17. Which of these areas of the basement significantly impacts your energy consumption (Select all that apply)

Tick all that apply.

☐ Ventilation
☐ Heating
☐ Lighting
Other: ☐ ____________________

18. Which of these problems have you encountered in your basement?(Select all that apply)

Tick all that apply.

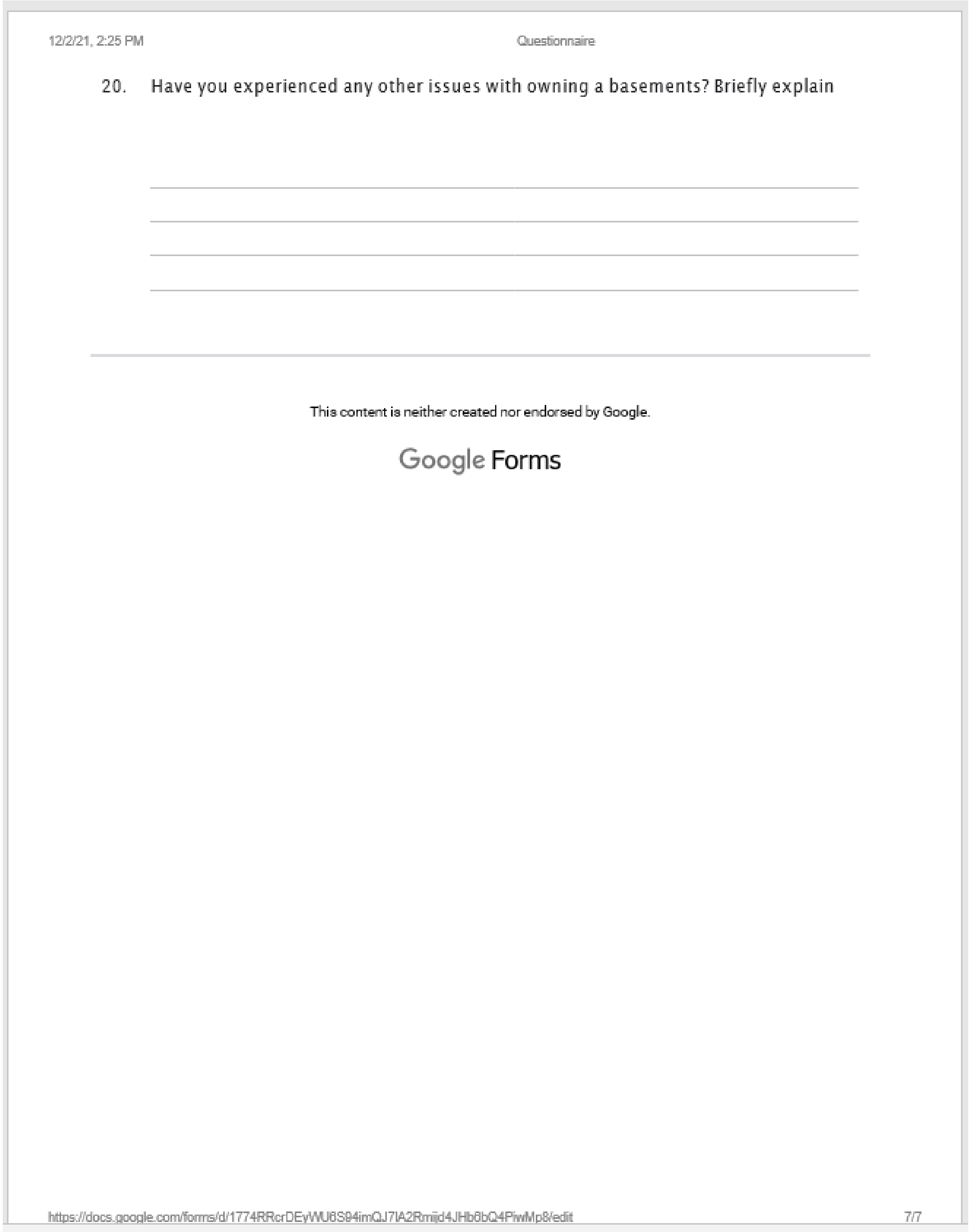
☐ Cracks in walls and slab
☐ Sinking basement floors
☐ Basement leaking and flooding
☐ Humidity and Molds

19. Which of these is your choice of insulation for your basement?

Mark only one oval.

○ Spray foam
○ Water proof paint
○ Bubble foil
○ Foam board
○ Fiber glass
○ Other: ____________________

https://docs.google.com/forms/d/1774RRcrDEyWU6S94imQJ7lA2Rmijd4JHb6bQ4PiwMp8/edit 6/7



12/2/21, 2:25 PM Questionnaire

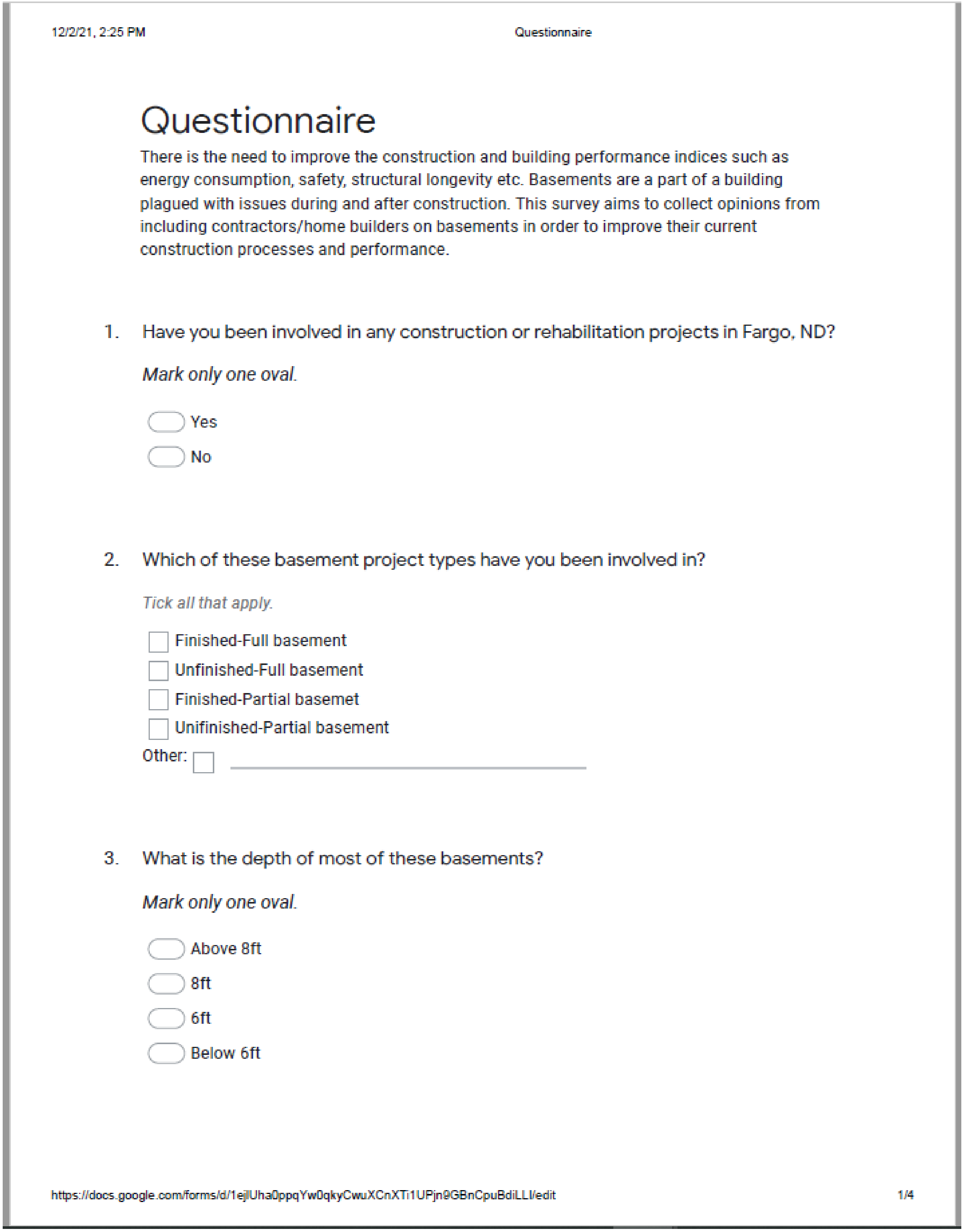
20. Have you experienced any other issues with owning a basements? Briefly explain

This content is neither created nor endorsed by Google.

Google Forms

https://docs.google.com/forms/d/1774RRcrDEyWU6S94imQJ7lA2Rmijd4JHb6bQ4PiwMp8/edit 7/7

B.3. Field Expert Survey Questions



12/2/21, 2:25 PM Questionnaire

Questionnaire

There is the need to improve the construction and building performance indices such as energy consumption, safety, structural longevity etc. Basements are a part of a building plagued with issues during and after construction. This survey aims to collect opinions from including contractors/home builders on basements in order to improve their current construction processes and performance.

1. Have you been involved in any construction or rehabilitation projects in Fargo, ND?

Mark only one oval.

○ Yes
○ No

2. Which of these basement project types have you been involved in?

Tick all that apply.

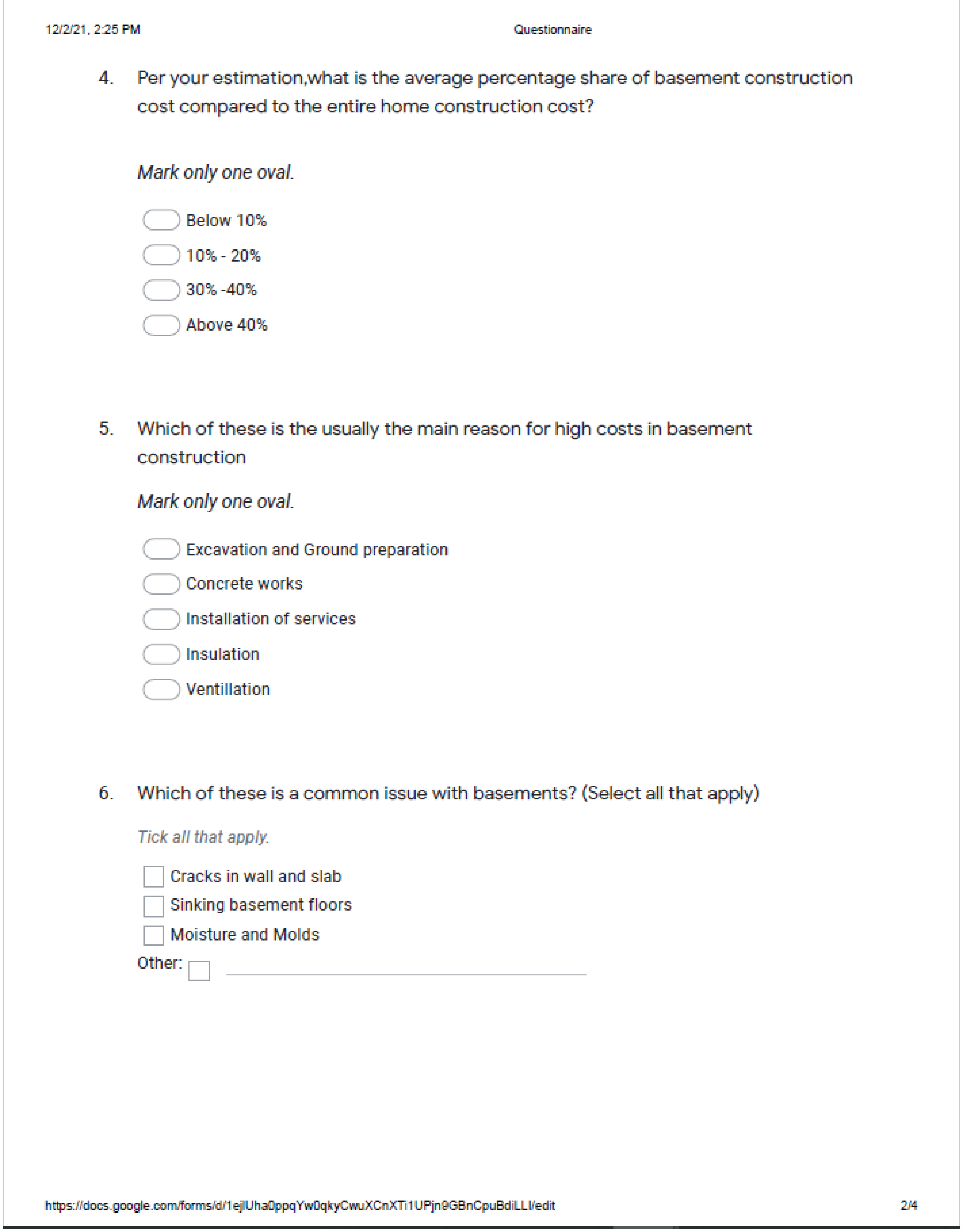
☐ Finished-Full basement
☐ Unfinished-Full basement
☐ Finished-Partial basemet
☐ Unifinished-Partial basement
Other: ☐ ________________

3. What is the depth of most of these basements?

Mark only one oval.

○ Above 8ft
○ 8ft
○ 6ft
○ Below 6ft

https://docs.google.com/forms/d/1ejlUha0ppqYw0qkyCwuXCnXTi1UPjn9GBnCpuBdiLLl/edit 1/4



4. Per your estimation,what is the average percentage share of basement construction cost compared to the entire home construction cost?

Mark only one oval.

○ Below 10%
○ 10% - 20%
○ 30% -40%
○ Above 40%

5. Which of these is the usually the main reason for high costs in basement construction

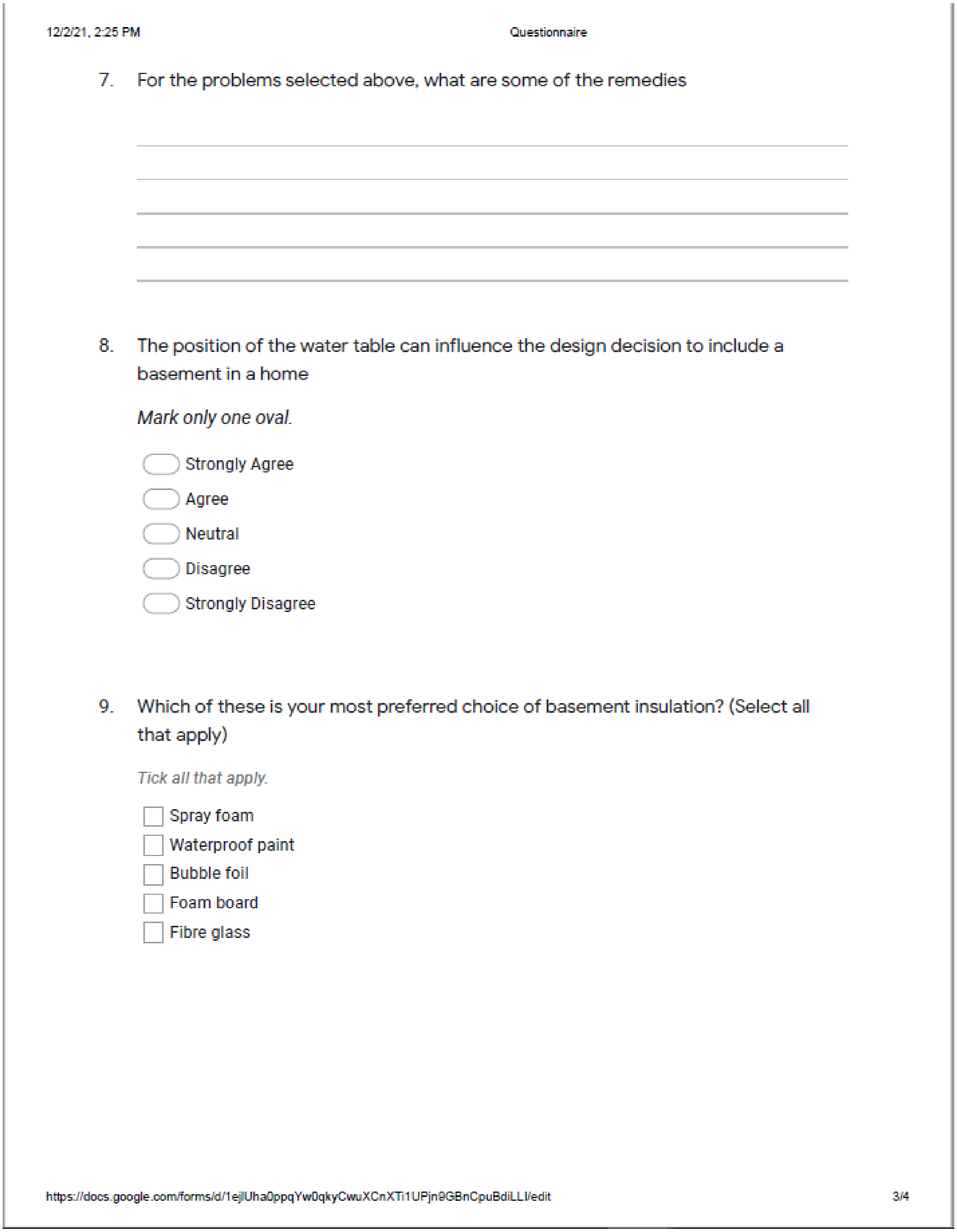
Mark only one oval.

○ Excavation and Ground preparation
○ Concrete works
○ Installation of services
○ Insulation
○ Ventillation

6. Which of these is a common issue with basements? (Select all that apply)

Tick all that apply.

☐ Cracks in wall and slab
☐ Sinking basement floors
☐ Moisture and Molds
Other: ☐ ______________________



12/2/21, 2:25 PM Questionnaire

7. For the problems selected above, what are some of the remedies

8. The position of the water table can influence the design decision to include a basement in a home

Mark only one oval.

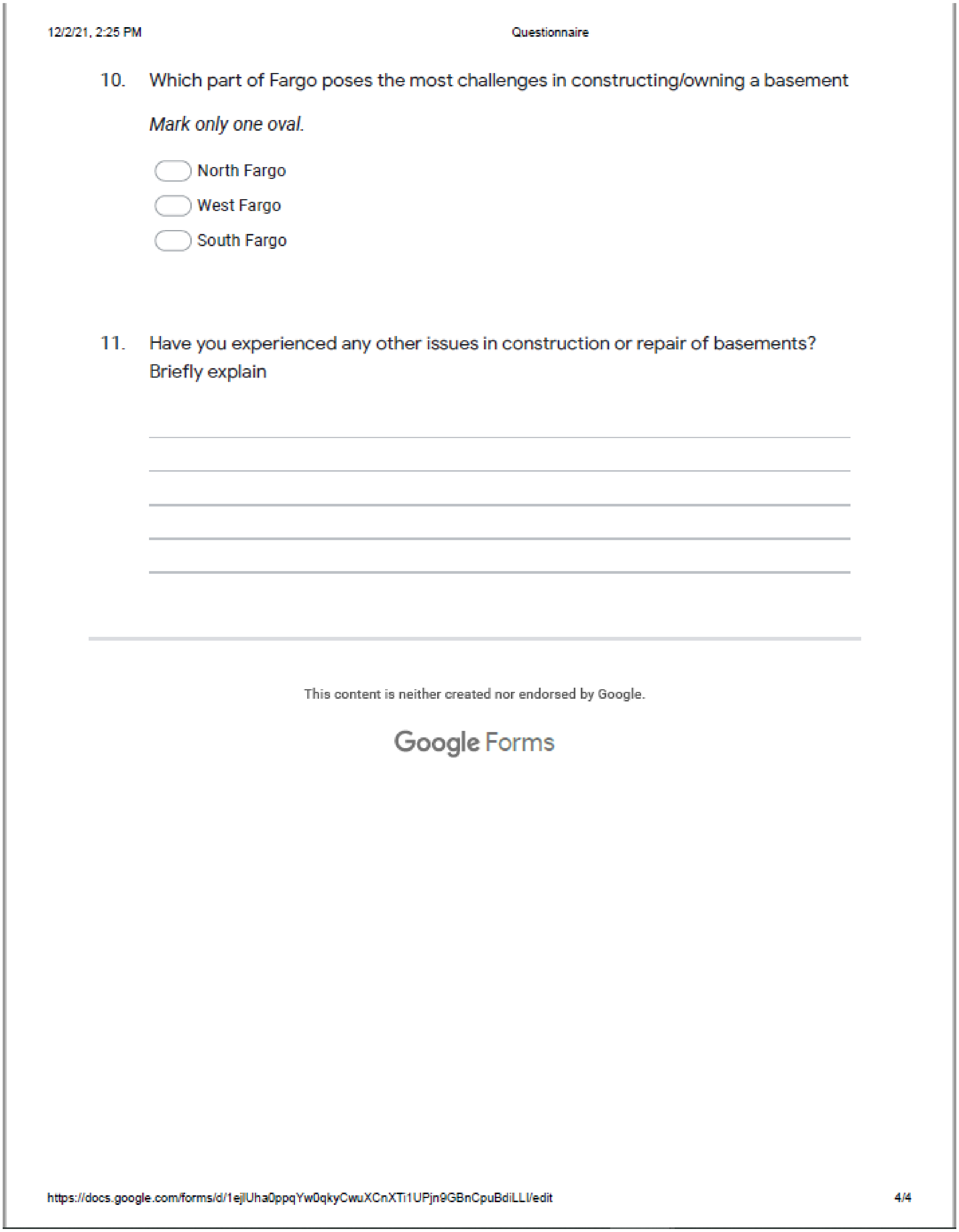
○ Strongly Agree
○ Agree
○ Neutral
○ Disagree
○ Strongly Disagree

9. Which of these is your most preferred choice of basement insulation? (Select all that apply)

Tick all that apply.

☐ Spray foam
☐ Waterproof paint
☐ Bubble foil
☐ Foam board
☐ Fibre glass

https://docs.google.com/forms/d/1ejlUha0ppqYw0qkyCwuXCnXTi1UPjn9GBnCpuBdiLLI/edit 3/4



12/2/21, 2:25 PM Questionnaire

10. Which part of Fargo poses the most challenges in constructing/owning a basement

Mark only one oval.

○ North Fargo
○ West Fargo
○ South Fargo

11. Have you experienced any other issues in construction or repair of basements? Briefly explain

This content is neither created nor endorsed by Google.

Google Forms

https://docs.google.com/forms/d/1ejlUha0ppqYw0qkyCwuXCnXTi1UPjn9GBnCpuBdiLLI/edit 4/4

B.4. Home Owner Survey Responses

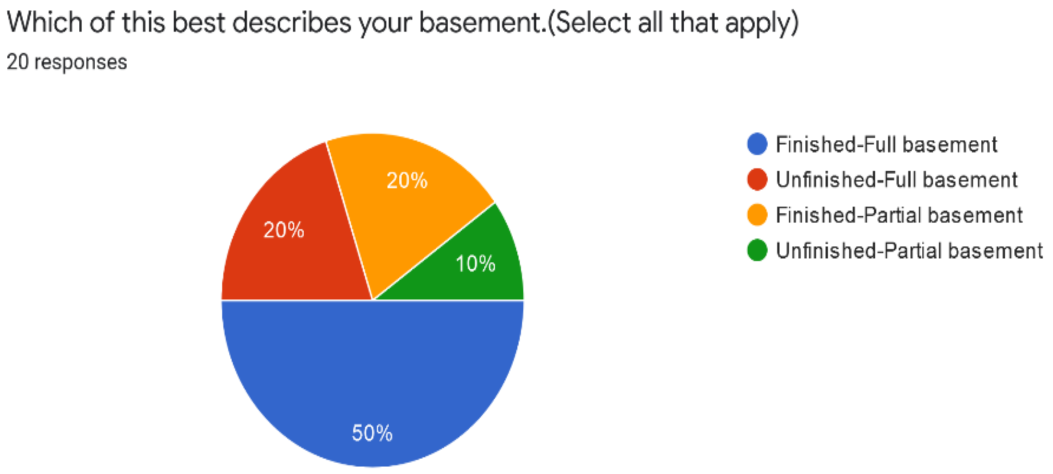


Figure B1. Home owner responses to type of basement owned

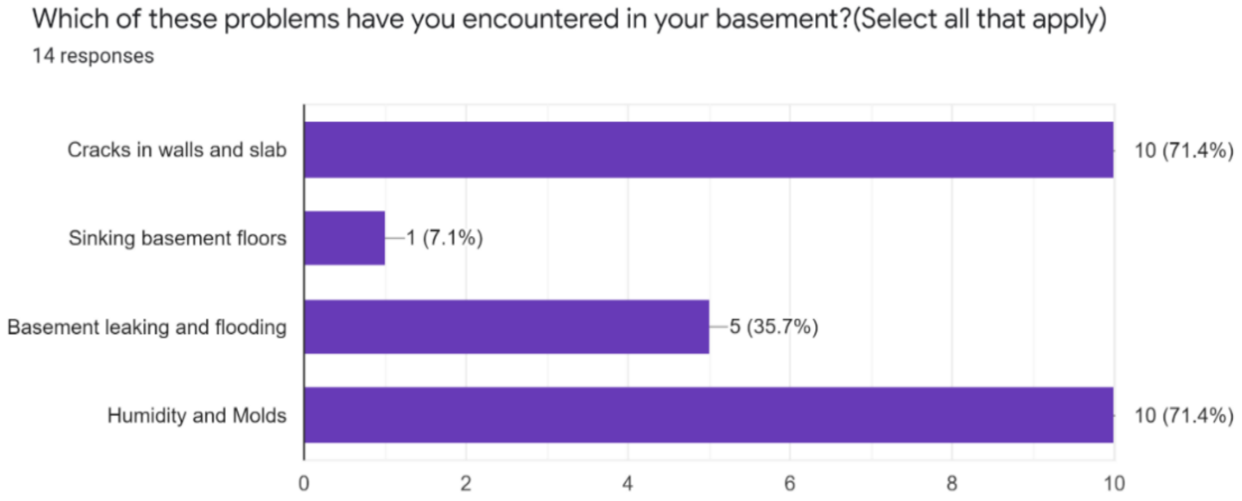
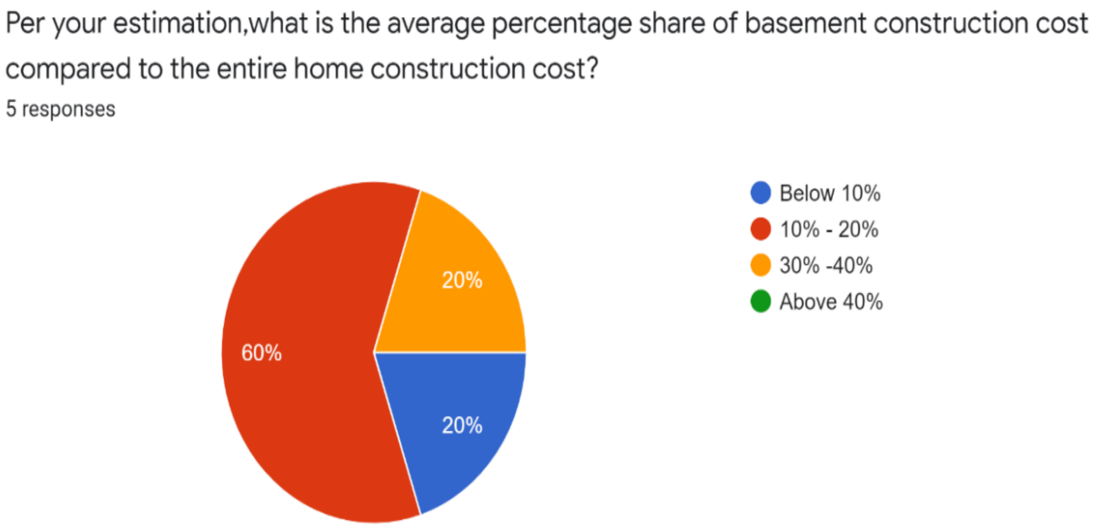
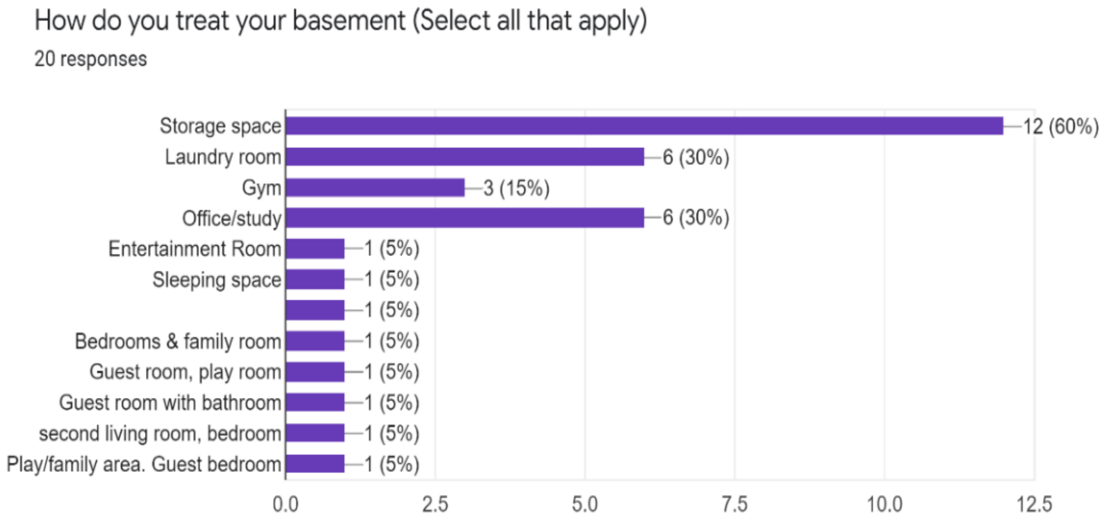


Figure B2. Home owner responses to type of basement related problems encountered.


Per your estimation,what is the average percentage share of basement construction cost compared to the entire home construction cost?

5 responses

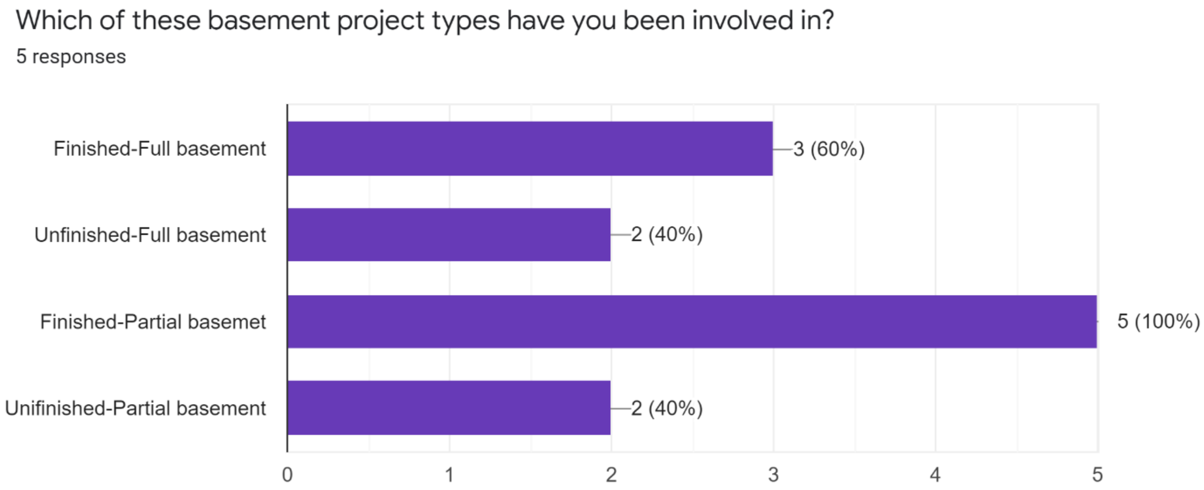
Figure B3. Home owner responses to percentage share of basement construction cost.


How do you treat your basement (Select all that apply)

20 responses

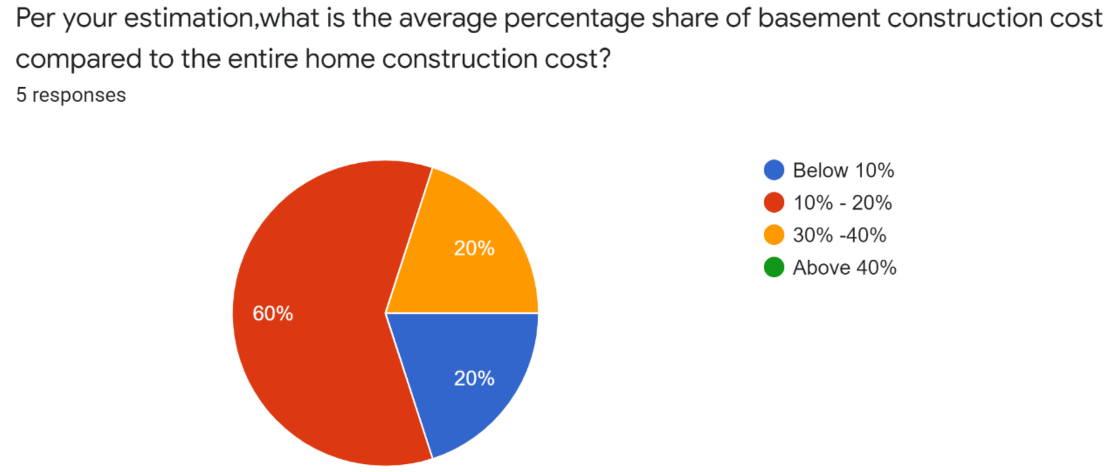
Figure B4. Home owner responses to use of basement.

B.5. Field Expert Survey Responses


Which of these basement project types have you been involved in?

5 responses

Figure B5. Field expert response to type of basement type built.


Per your estimation,what is the average percentage share of basement construction cost compared to the entire home construction cost?

5 responses

Figure B6. Field expert responses to percentage share of basement construction cost.

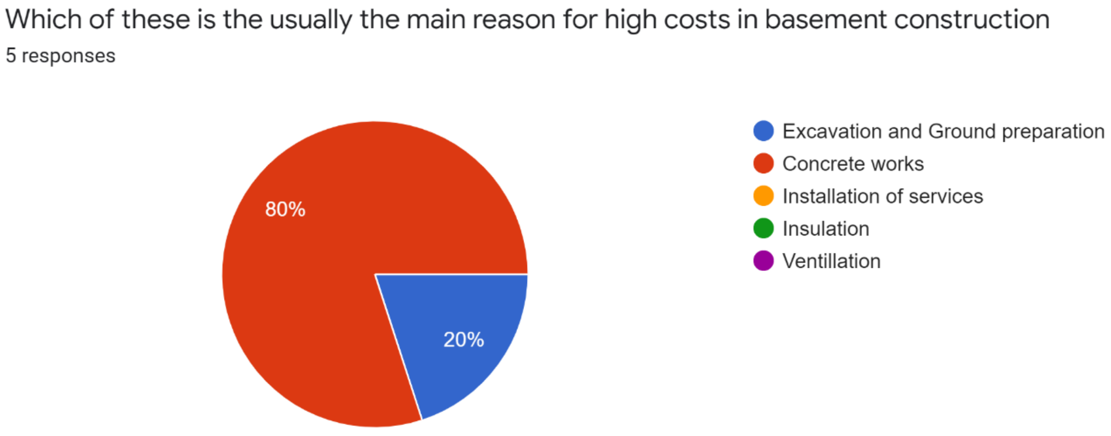


Figure B7. Field expert responses to reason for high basement construction cost.

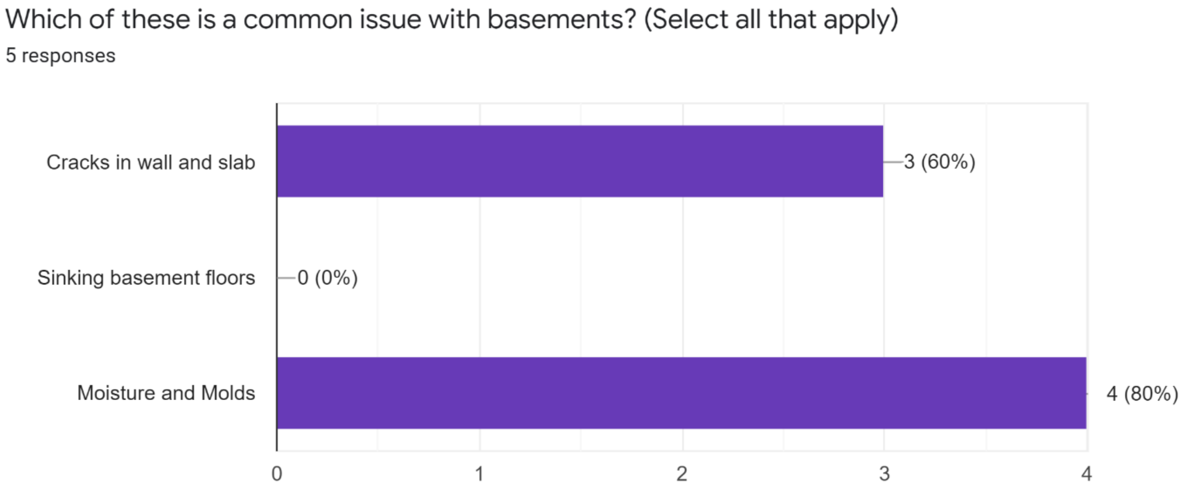


Figure B8. Field expert responses to common basement issues encountered.

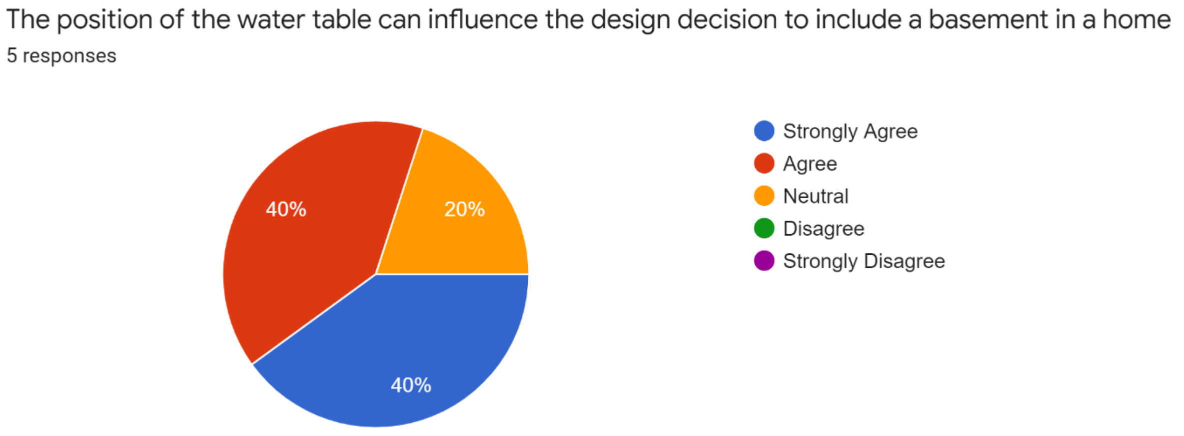


Figure B9. Field expert responses to the influence of water table on basement design decisions.

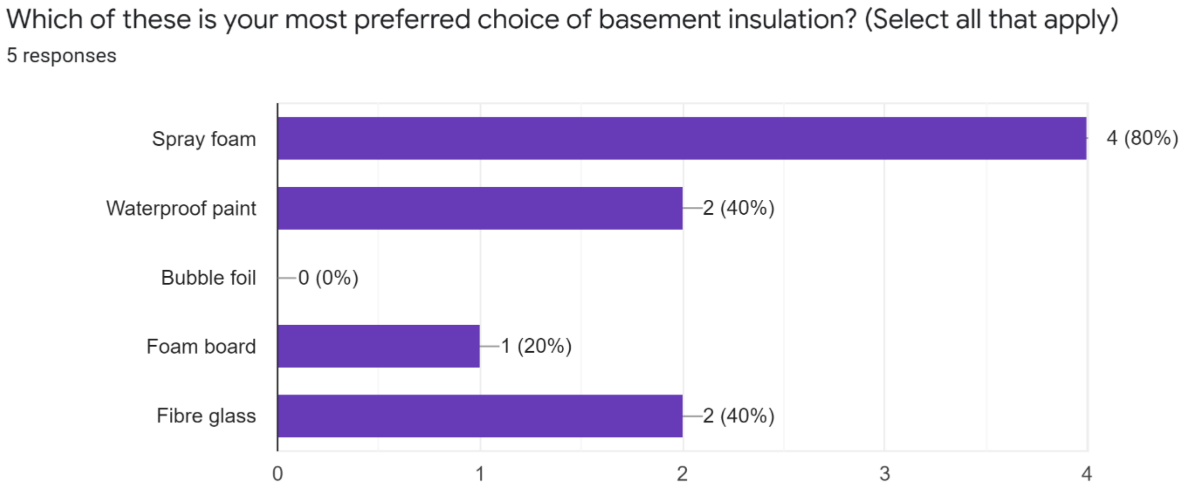


Figure B10. Field expert responses to the preferred choice of basement insulation.

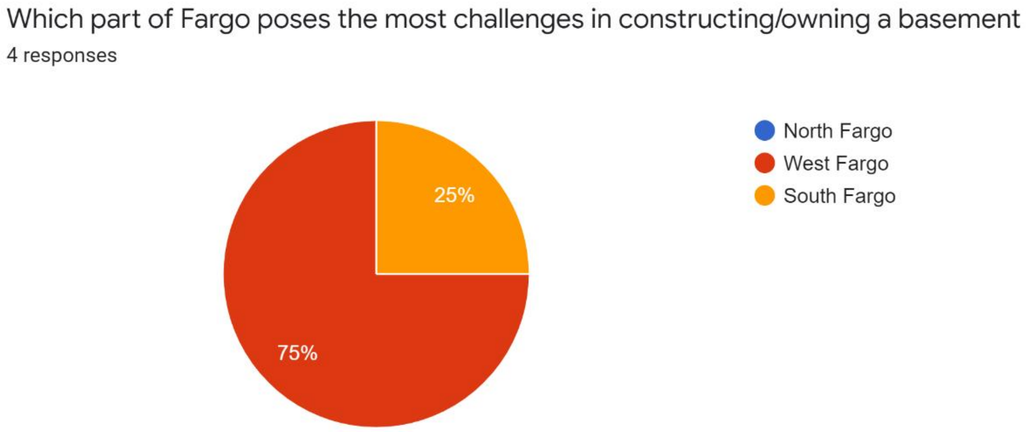


Figure B11. Field expert responses to the most challenging basement construction location.

APPENDIX C. IRB APPROVAL FORM

NDSU NORTH DAKOTA STATE UNIVERSITY

October 14, 2019

Cyril Ahiable
Construction Management and Engineering

Re: Your submission to the IRB: “Improving the Environmental Impact of Basement Construction Using BIM”

Co-Investigator(s) and Research Team: n/a

Thank you for your inquiry regarding your project. At this time, the IRB office has determined that the above-referenced protocol does not require Institutional Review Board approval or certification of exempt status because it does not fit the regulatory definition of ‘research involving human subjects’.

Dept. of Health & Human Services regulations governing human subjects research (45CFR46, Protection of Human Subjects), defines ‘research’ as “…a systematic investigation, research development, testing and evaluation, designed to contribute to generalizable knowledge.” These regulations also define a ‘human subject’ as “a living individual about whom an investigator (whether professional or student) conducting research:
(i) Obtains information or biospecimens through intervention or interaction with the individual, and uses, studies, or analyzes the information or biospecimens; or
(ii) Obtains, uses, studies, analyzes, or generates identifiable private information or identifiable biospecimens.”

It was determined that your project does not require IRB approval (or a determination of exemption) from NDSU. The data collected is not about the individual respondents, but their company’s practices.

We appreciate your intention to abide by NDSU IRB policies and procedures, and thank you for your patience as the IRB Office has reviewed your study. Best wishes for a successful project!

Sincerely,

Kristy Shirley

Kristy Shirley, CIP; Research Compliance Administrator

For more information regarding IRB Office submissions and guidelines, please consult https://www.ndsu.edu/research/for_researchers/research_integrity_and_compliance/institutional_review_board_irb/. This Institution has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.