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Sacral Sound-Engineering

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Organologic and campanologic acoustical problems due to applications to sacral objects are characterized on ground of numerous reviewed publications and engineering reports. Participation of several involved research centres, mostly Polish, at solving these problems is evaluated. Some desirable future developments are indicated. Appendices bring examples of documentation on selected investigated objects.

Keywords: acoustics of church interior, organology, campanology.

1. Introduction

The title of this article may seem unclear and, therefore, requiring a preliminary comment. To start with, let us devote some attention to the word *ENGINEERING*.

Dictionaries have it derived from the French *ingénieur*, but it often is associated with the English *engineer*, and those two terms are by no means synonymous. We must, therefore, go back to its Latin roots. Etymologically, the term *engineering* undoubtedly derives from the words *ingeniosus – talented or ingenious*, and *ingenium- innate ability or nature*. The dictionary, however, gives another four specific meanings: a) *creative spirit, genius, talent, brightness*; b) *common sense, imagination*; c) *genius = brilliant man*; d) *witty, wise idea.* It is difficult to see here anything related to a concept such as the profession of engine operator, as one of the main meanings of the English word *engineer* indicates, which clearly discords with the concept of sacral sound and can be, therefore, omitted in this context. Thus, etymological considerations show that no internal contradiction is present in the title of the article, so the proposed medley of terms seems acceptable.

We also need to recall the history of the term Sound-Engineering, used as another part of the title, to realize how vague, even until recently, something

that today is taken as obvious, could be. The term was completely unknown in Polish technical literature forty years ago. The scope of topics included within it today was previously known as Electroacoustics, or more generally Acoustics, which did not actually reflect its semantic nature. The rapid development of technology, especially electronics, in the second half of the 20th century created the need for adequate naming of that newly shaped and defined area combining technical and humanistic knowledge and skills.

To meet that need, especially urgent in the didactics of a university, foreign language comparative examples had to be consulted. Anglo-Saxon literature used the closest semantic equivalent, *audioengineering*. In spite of the fact that, unfortunately, the Latin verb "audio" in first person singular has been incorporated into it, the term has spread so extensively that the possibility of adopting a more correct linguistic form of *sound engineering* was prevented. In Germany, two professional terms for specialists in that field functioned simultaneously: *Tonmeister* and *Toningenieur*, which differ slightly in profile; however, an appropriate name for the area has not been coined. Incidentally, the term *Tonmeister*, used in the narrower sense as a professional title, has been adopted and is used by some universities not only in Germany but also in Poland and England, as a result of which a new word has even been created: "Tonmeistering" – a blend of German and English, used to refer to sound engineering. In France, the term *Ingénieur du Son* was introduced as early as the thirties, and also the form *ingénierie* – meaning engineering – was used (Jean–Louis, 1955).

Based on those and other examples of relevant terminology, the Polish name of the area was proposed in 1982: *Inżynieria Dźwięku* (i.e. Sound Engineering), with the subject matter and curriculum for that specialization having been defined well before then. At the same time, at the Electronics Faculty of Gdansk University of Technology (GUT) the Sound Engineering Department (ZID) was established, and its name was approved by decision of the Faculty Council and accepted by the University authorities.

Sound Engineering was defined as: resolution of issues of sound studio technology and sound operating technology on the basis of the knowledge of the fundamentals of acoustics, psychophysiology of perception, basic music theory, and musical instrument studies. The above wording is based, among other things, on the definition of the word *sound* given by A. Rakowski (Rakowski, 1967), and in particular on the interpretation of the term *musical sound*, which he defines as *sound with a definite pitch*. For the purpose of this article, the author contents himself with the realm of musical notions in European culture, whilst atonal sounds (with indefinite pitch), although used in European music increasingly frequently and although very important in the context of sacral sounds of other cultures, are not included here.

At some stage, ZID PG ensured that the entry "sound engineering" was included in the PWN (Polish Scientific Publishers) technical dictionaries published at that time, and the results of scientific research, reflected in publications, as

well as the results of teaching, in the form of many educated graduates of the specialization, have initiated rapid popularization of that term on a national scale. Sound Engineering symposia organized by the Department, and later by the Chair and by various national centres for research and teaching, both nationally and internationally, have contributed to the universal acceptance of the once new term.

Depending on how the knowledge and skills in the field of Sound Engineering were applied, thematic areas were distinguished within it, such as: speech and music sounds, propagation and transmission of sound, sound in radio and television, sound in auditoria, sound in architecture and urban planning, protection against undesirable sound, etc. Sacral sound was not included on that list; however, it was not because of an underestimation of the importance of that subject in the context of the whole range of applications of Sound Engineering. On the contrary, sacral sound, after all, is involved in most of the areas represented in Sound Engineering. However, the issues of Sacral Sound, even though historically the oldest and playing the most important culture-producing role in the field of Acoustics, were formerly investigated by dispersed creators, mostly unknown and acting "*ad maiorem Dei gloriam*". Thus, the subject matter was poorly presented explicitly, under adequate denominations. The dispersion of creators is often still a valid problem, which makes it all the more desirable to characterize the topic in more detail.

The term Sacral Sound itself, which has been used as the second term of title, also requires a comment. The adjective "sacred", which derives from the Latin *sacer – sacred, consecrated*, is used, in particular, to designate a connection with a religious group. In this sense, we refer, for example, to Sacral Architecture or Sacral Acoustics, which are thematically closely related to Sound.

In ancient times, Sacral Architecture dominated the entire field of Architecture. Preserved architectural monuments include mostly temples and the sparse literature associated therewith. The state of preservation of such monuments permits excellent exploration of the construction knowledge and skills of ancient architects. However, it does not allow a similar assessment in terms of sound engineering. Although we can see certain structural solutions, no doubt intended to improve the intelligibility of speech in the interior of temples, such as holes in ceilings, or "acoustic vases" in walls, which reduce the duration of reverberation, there is no general information about the acoustics of those buildings due to the fact that the equipment of the interiors was not preserved. In that respect, considerations devoted to acoustics from preserved works of ancient engineers and scientists, first of all of Aristotle and Vitruvius are more valuable. They contain the earliest theories of sound propagation resulting from scientific experiments of an engineering nature, as well as basic concepts of the theory of musical scales.

The importance of such "primeval sound engineering" becomes readily appreciable upon the realization that after more than twenty centuries of research on

sound, new and valuable scientific achievements, applicable to sacral acoustics, are still being made.

As for the name Sacral Acoustics, it must be admitted that using it with reference to ancient times may be found objectionable as the word *ACOUSTICS* appeared only in the 17th century, when the term was introduced to denominate a separate branch of physics by Solomon Reyher in 1693. Speaking of the genealogy of sound engineering, Wajdowicz mentions Athanasius Kircher (1602–1680), a monk endowed with extraordinary inventiveness and showing engineering capabilities that were well ahead of the contemporary state of knowledge. He studied, among other things, the properties of sound propagation in buildings, and on the basis of his research, an acoustic funnel device was designed in a Jesuit monastery in Austria (Wajdowicz, 1966).

2. Scope and purpose of the article

Sacral buildings, which acoustic properties are often the subject of study and research, are temples, especially their interiors, as well as musical instruments connected with them: organs and bells. Because of the far-reaching differences in the construction of temples of different religions and denominations, this article refers mainly to Christian constructions, which is justified by the purpose of this article.

The primary purpose of the article is to show the effects that an engineering approach to sacral sound problems has exerted on the state of knowledge and applied research in the country throughout this area, and especially in the formation of the main thematic groups:

1) inventory of sacral buildings,
2) acoustics of temple interiors,
3) sound reinforcement systems in church interiors,
4) organology,
5) campanology.

One could, of course, point to topics related to sacral sound and not included in the above list, but from an engineering point of view, it would not be justified.

The secondary objective is to characterize the status of national research on the problems emerging in those groups and to provide information about the research potential of individual research centres in the country, comparing it against corresponding international developments. That information results from a review of publications, especially those cited in the Bibliography, and from the experience accumulated over the last thirty years at the ZID (cf. Appendix C). Therefore, the article is, for the most part, of a review nature. Among the cited sources of information, a number of publications tackling the subject from a purely historical or aesthetic perspective were intentionally omitted as, to date, they had been prevalent among the works devoted to sacral acoustics,

which is conspicuous when viewing the relevant literature. Therefore, this article takes into account publications of a primarily engineering nature, thematically corresponding to the five groups defined above.

Finally, a specific group of architectural publications was omitted, devoted to designs of sacral buildings that are entirely new, both conceptually and stylistically, and seem independent of religious traditions. This thematic group requires a separate investigation as the sources in literature existing so far do not provide sufficient material for deeper analysis and thus cannot be included in actual considerations.

3. Engineering research problems

A sound engineer who works in any of the aforementioned five thematic groups must begin by identifying and taking inventory of the premises, which is typically a highly labour-intensive task. In that case, valuable help can be provided by publications containing the results of prior inventory taken individually with respect to a given building or, collectively, in premises with similar properties. In that respect, even cursory inventories, giving only statistical information on selected features of the building, are helpful.

3.1. Inventory of sacral buildings

In the generally available literature, there are rare publications attempting to take inventory of sacral buildings on a global scale (Price, 1983); however, there are works devoted to such attemps made in individual countries e.g. Switzerland (Billeter, 1992), France (Dufourcq, 1969), Slovakia (Gergelyi *et al.*, 1992), Poland (Gołos, 1992; Smulikowska, 1993), Germany (Schäfer, 1982). The initial sources of information about Polish sacral buildings are specialized cartographic publications, as well as numerous historical publications (Januszajtis, 2009). In relation to organs or bells, however, the main national source is the documentation stored by the National Heritage Board of Poland (ODZ) established by the Ministry of Culture [101].

ODZ record logs contain basic information about the building, the gathering of which does not require specialized test equipment. The nature of that information is illustrated with examples of completed logs shown in the Appendices: organ log – cf. Appendix A, bell log – cf. Appendix B.

On the other hand, in signed publications, in addition to basic information, more detailed data is provided, which had been obtained in the course of specialized research, measurements with appropriate apparatus, registering the results of measurements and recordings, as well as analysis of results.

The most essential element of the engineering knowledge and skills applicable to sacral music is undoubtedly the knowledge of musical instruments. Among

the many types of musical instruments used to produce sacral sound, particular attention should be paid to bells and organs. Usually, both are organically tied to the temple, or are, practically speaking, permanently embedded in its structure, even though in the terminology of historical heritage they are classified as "movables". Obviously, the considerations should also include portable organs (positive organ, portative organ, and regal) which are sometimes used in temples, as well as altar bells (hand-held, wall-mounted or suspended in tripods) commonly used in the liturgy.

When taking inventory of buildings, one must remember that the quality of sacral sound produced by instruments perceived by the listener depends to a large extent on the acoustical conditions inside the temple. Therefore, the primary task of a sound engineer involves examination of the existing acoustical conditions in the temple and possible improvement or redesign thereof.

3.2. Acoustics of temple interiors

Improvement of speech intelligibility and sound quality in a temple is the most common objective of work undertaken by researchers of the acoustic properties of sacral interiors. That objective is difficult to achieve, especially in large interiors. Hence, numerous publications present global research on selected interiors of that kind (Anderson *et al.*, 1985; Doelle, 1972; Fearn, 1975; Giulianini *et al.*, 1985; Klepper, 1995; Lewers *et al.*, 1984; Raes *et al.*, 1953). Such publications often serve as a signpost for authors who undertake further work of a similar nature in their countries (Engel *et al.*, 1992; Sankiewicz, 1980). They refer to numerous specific architectural structures, but often aim at generalized observations and conclusions (Kosala, 2004; Witkowski, 1980; Wróblewska, 2000). They also aim at implementing appropriate research methods and measurement techniques, sometimes in opposition to the requirements imposed by liturgy and contemporary construction conditions (Niemas *et al.*, 1998; Tzekakis, 1977).

Generalized conclusions include, primarily, recognition of the fact that reverberation time is the parameter that determines the quality of the interior, and, moreover, a definition of the indicators of acoustic quality (Engel *et al.*, 2004; 2007). The author of this article believes that the use of such indicators in the sound engineering practice does not have a chance of success due to the excessively far-reaching variety of sizes and shapes of modern church interiors. It is worth mentioning that the current liturgical requirements, introduced in 1965 by the Second Vatican Council, gave designers complete freedom of choice in that respect.

A series of international scientific and technical conferences, entitled Sacral and Monumental Architecture, held every two years in Bialystok, have created a platform for sharing ideas and creative discussion among architects and acousticians – sound engineers. A review of talks presented at those conferences does

not suggest, however, that crucial progress has been made towards improving the acoustic quality of new buildings. Treatment of a sacral interior as a large space intended for verbal and musical output of a solely liturgical nature seems too far-reaching a simplification. After all, the greatest organ instruments of the modern world are found in churches, and hopefully this will be the case in the future. Therefore, one should bear in mind that sacral interiors will be also used for giving secular concerts, and consequently architects and acousticians should take into account the acoustic requirements arising from the conditions for good sound of the organ inside a church.

Also, solutions to acoustic problems that occur in old-time buildings have not been sought. Those problems were abundant during the intense post-war reconstruction work on churches totally or partially destroyed by war, but also today they exist in the form of unresolved restoration issues and, for example, a lack of understanding of the consequences of choosing between a single-space and multiple-aisled church (Deurer, 1981), or due to the lack of sufficient knowledge of the mechanism of sound absorption of certain types of resonance systems, as indicated by several authors (Sankiewicz, 1986; Trochidis, 1982; Tzekakis, 1977). Acoustic investigations of churches, especially of large ones, to determine their properties with respect to varying locations of sound source and listener position, are rarely conducted (Stauskis, 2002). There is also no deeper analysis of acoustic and visual criteria for the location of the organ, choir, pulpit and other functional elements in the interior of the church. Noticing a problem in a single investigated building does not compensate for the general neglect thereof by other authors. Pulpits and confessionals that are no longer used today, located at the sound-reflecting walls of many churches, are a silent reminder of the failure to develop a proper concept of their adaptation to the current demands of the liturgy.

3.3. Sound reinforcement systems in church interiors

At this point, it is worth showing the purposefulness of the distinction between sound reinforcing- and sound amplifying-system. The former occurs when the sound source is heard directly or "live" by some listeners present in the same area as the source, while by the remaining listeners (more distant from the source) through an amplifying (and correcting) device and a network of loudspeakers that radiate the sound. The latter, on the other hand, occurs in more general cases, when, instead of a source radiating live sound, either a pre-recorded sound is used (which is not the case in the liturgy), or when a live sound source is located in an acoustically separated space and cannot be heard directly.

There are a number of foreign publications devoted to sound reinforcement in temples of different denominations (Carvalho, 1995; Catania, 1970; Klepper, 1970; Popescu, 1980). However, little is devoted to that subject in domestic publications, and problems to be solved are plentiful.

Sound reinforcement systems benefit from the undoubted progress that has been made since they were first introduced in the interiors of churches, especially of large ones, in the art of sound reinforcement devices, particularly with regards to the improvements introduced to the electro-acoustic channel components, including speakers with specific directional properties, but they still fail to meet the growing demands from the audience gathered in the church. One has to take into account the fact that the modern listener is not only sensitive to proper comprehension of the words transferred by the sound reinforcement system, but also to other properties of the perceived sound, primarily directional ones. The system should, therefore, distinguish between the direction of reinforced sounds produced by a singing priest at the altar from the direction of vocal responses produced by an organist in the organ loft. Other situations in which the listeners require consistency of directions between the sound image perceived directly and the image created by the sound reinforcement system include the sound of prayers said in the porch during the greeting before the ceremony of baptism, and the sounds accompanying the movement of a procession inside the church, among others. Achieving consistency of directions is particularly needed in large and divided church interiors, where listening to reinforced sounds that have directional features inconsistent with the reality is tedious for the listener. The problem is when some of the sound information is completely devoid of reinforcement and becomes inaudible to listeners, as is the case in the currently-used systems.

The development of multi-channel sound reinforcement systems with consistent acoustic and visual directionality, taking into account the location of various sound sources, including currently inactive pulpits, would be a rewarding, if difficult, design task for sound engineers. Such systems should be equipped with automatic control of the reinforcement level and the degree of frequency characteristics correction to compensate for the changes in the amount of attendance in the church and other factors changing the interior acoustic environment (noise levels, unnecessarily open microphones, etc.).

It is worth mentioning that the investigations of acoustic qualities of church interiors, discussed in Subsec. 3.2, conducted without taking into account the sound reinforcement systems operating therein, do not have much significance, since the use of such interiors without sound reinforcement is, practically speaking, no longer even considered.

3.4. Organology

Among publications concerning organ sounds numerous works of foreign and domestic authors were devoted to analyzing processes of generation acoustic vibrations in aerophonic instruments, i.e. in organs. That subject, however, belongs rather to the Theory of Vibrations than to Musical Instrument Studies,

and therefore will be mentioned here only in relation to any works that offer practical applications to the church organ.

Required, however, is information on acoustical properties of the most valuable, famous organs, as well as their characteristics analyzed in professional litterature (Adelung, 1972; Billeter, 1989; Goebel, 1967; Hardouin, 1973; Mroczkowski, 1995; [104]).

A specific group of publications of German origin document the organs that existed in the territory formerly belonging to Germany, in the North (Renkewitz *et al.*, 1984) and South-Western Poland (Burgemeister, 1973). For obvious reasons, their authors, having direct access to German archives, had an easier task in the development of publications than domestic authors.

The date which marks the start of intensive development of engineering research on organs in Poland is 1971, when the two-volume "Construction of the Organ – an introduction to the inventory and documentation of historic organs in Poland" was published. The author, Father Prof. Jan Chwałek, created a unique work in Polish organologic literature, which contained the full range of knowledge on the construction of organ instruments (Chwałek, 1971). It paved the way for researchers taking on the topic from an engineering point of view, and has created conceptual and terminological tools to foster interaction between acousticians, on the one hand, and organ builders and art historians documenting the history of individual instruments and examining the artistic value of organ-cases, on the other (Smulikowska, 1993).

It must be said that – as was noted in the editorial preface by Bolesław Bielawski, director of the National Heritage Board of Poland, the publisher of the work in question, – art historians working with the Board (Prof. Jerzy Gołos, Marian Dorawa, MSc, and others) did not foresee the urgent need to conduct engineering research on organs until the sixties. In response to the initiative of the Board, thematically relevant research institutions, based in related university departments, have undertaken, starting in the late seventies, work of the expected nature.

For obvious reasons, the individual centres first explored locations situated in nearby regions of the country. A forum for the presentation of their work and exchange of experiences and views was created at the then National College of Music in Gdańsk, which is now the Stanisław Moniuszko Academy of Music, in the form of scientific sessions entitled "The Organ and Organ Music" held every two years. Works presented at those sessions, which are published in a special book series edited by Janusz Krassowski, reflect the development of knowledge about the organ in Poland, dating back to the beginning of 1977, including the development of sound engineering expertise.

As a result of that forum, numerous works by Father Prof. Jan Chwałek were published, particularly significant as milestones in the scientific development of the Chair for Musical Instrument Studies of the Institute of Musicology of the Catholic University of Lublin. The next stage of that development is marked by publications issued by the Catholic University of Lublin (Kapeć,

1981; Pietrzyk, 1988; Sudak, 1990; Szymanowicz, 1990) and the successive volumes of the specialized publication series "Studia Organologica" initiated and edited by prof. J. Chwałek and continued by prof. M. Szymanowicz.

In the meantime, in Gdańsk, numerous authors from the Academy of Music in Warsaw (Erdman, 1978; Rakowski, 1963), the Academy of Music in Gdańsk (Gudel, 1978), a large group of contributors from ZID and individual contributors from various centres, including abroad, presented their contributions. They were of importance for the development of engineering knowledge about the organ. Some of those were particularly valuable from the standpoint of sound engineering (Orlinski, 1984; Walcker–Mayer, 1982; 1991).

In the seventies and eighties, the authors from ZID sought a method of research that would enable the use of comparative analysis of the results gathered with respect to various instruments examined in church interiors of varying acoustics. The prototype was an earlier method developed by Werner Lottermoser (Lottermoser, 1955). Other methods proposed at a later time, based on the theoretical justifications given by their authors (Jannson *et al.*, 1975; Leipp, 1977; Plomp *et al.*, 1984; Sundberg *et al.*, 1976), have been cited frequently in global literature; however, they did not prove to be useful for direct application in practice. A method involving comparison of the shape of reverberation frequency characteristics inside the church with the shape of the spectral density characteristics integrated during the playing of a sound test previously recorded in the examined interior, in the *organo pleno* register of the instrument, has found practical application. The method was developed in the late seventies at ZID, and the first results of comparative tests of the properties of several organ instruments were presented in 1980 at the ICA Congress (Budzyński *et al.*, 1980) and in subsequent publications (Budzyński, 1987).

An important contribution expected from sound engineers investigating the organ is to record the sound in such a way that those recordings are documentation that can be used to reconstruct the sound features of the instrument in the event it is damaged or destroyed, as well as for the purposes of comparative studies of the sound of various organs. Many researchers, including investigators conducting the studies mentioned above, encountered conceptual and technical difficulties in determining how to document the sounds that characterize a given organ instrument (Angster *et al.*, 1995; Stepanek *et al.*, 1994). While the sound recording itself, first analogue and later digital, conducted on a portable recorder did not cause any problem, the choice of microphone techniques, especially the number and characteristics of the microphones, their positioning inside the church, the system for mixing and spatial and temporal averaging, as well as selecting the right piece of music as a sound test, were challenging tasks (Budzyński *et al.*, 1997; Kaczmarek, 1987; Sankiewicz *et al.*, 2007).

The aforementioned in-depth engineering studies, fringing upon musical instrument studies and theory of vibration generation, were performed at ZID at a specially prepared laboratory station. The dynamic characteristics of vibration

generated in selected flue pipes of different construction were tested. Sound pressure of the sound produced, as a function of air velocity through the mouth, was measured; velocity was determined using a thermoanemometer placed in the lip (Perucki, 1990). It should be noted that in the practice of organ research and publications of the results of such research, too little attention is paid to the measurement of pressure in the bellows and wind chests. For example, the logs of ODZ do not contain a section for recording the results of such measurements at all (see e.g. Appendix A). Meanwhile, it is an important value, which determines the choice of the operating point on the dynamic vibration characteristics of the individual pipes, especially their operation during overblowing, and, consequently, their timbre. That value is sensitive to deviations, caused by material wear, or accidentally, from the nominal value set by the organ builder, and therefore should be accurately controlled. Characteristic in that regard is the warning inscription placed by the organ builder doing repair work on the instrument ("It is forbidden to pose anything on the bellow bag or to remove bricks" – see Appendix A, section 32, row 2 and 3).

The rapid development of computer technology in general is expected to cause the existing organ testing methods to be replaced with newer ones, also taking into account new developments and techniques which will probably be applied to the organs constructed in the near future. Research in that area was published in the series "The Organ and Organ Music" (Chwałek, 1997; Gudel, 1978; Kostek, 1991; Orliński, 1984; Walcker–Meyer, 1982; 1991), and developed particularly intensely at the Department of Sound and Vision Engineering, Gdańsk University of Technology (Budzyński *et al.*, 1995; Kostek *et al.*, 1990; 1993; Kostek, 1990; 1991; 1992; 2007; Kaczmarek, 1995; 1999; Zieliński, 1997).

3.5. Campanology

The term campanology, coined from Italian or Spanish word *campana* – bell, is already well known in the literature [105].

The study of bells has long been an important theme in world literature in the field of acoustics. In order not to add too much volume to the Bibliography, it contains only a few selected publications (Bagot, 1986; Ellerhorst, 1957; Rossing, 1984) representing the basic knowledge needed to work on this topic. That knowledge is supplemented by relevant publications by domestic authors, both historic and contemporary. In the period immediately after World War II, Poland lacked facilities for acoustic investigation of bells because of the enormity of losses suffered by the national campanologic resources (Gołos *et al.*, 2000).

The motivation to undertake experimental research by acousticians in Gdańsk was the reconstruction work done on the carillon at St. Catherine's Church in Gdańsk. In 1989, in the first stage of reconstruction, a new 37-bell instrument was put into operation, and soon the results of the analysis of its tuning

were published. That opportunity was also taken to examine the provisionally reconstructed (14-bell) carillon in the Gdańsk Town Hall tower (Budzyński *et al.*, 1993), and then the inactive carillon (34-bell) at Jasna Góra in Częstochowa (Sankiewicz *et al.*, 1994). Upon completion of the second stage of reconstruction of the St. Catherine's instrument, that is after it was expanded to 49 bells, and after definitive reconstruction of the Town Hall carillon (37 new bells) in 1998, Gdańsk became the only city in Poland equipped with high value bell instruments, complete with consoles (manual and pedal), allowing virtuosos to give concerts; also outfitted with automatic control for replaying of pre-registered melodies, and associated tower clock devices (Szychliński, 2009). Those instruments are excellent research facilities, from an engineering point of view, giving rise to numerous publications about them (Budzyński *et al.*, 1993; 1997; 1999; 2000). Based on the experience gained in the course of work in Gdańsk, the authors at Multimedia Systems Department GUT deepened the scope of problems being investigated and expanded the scope of the research throughout the entire country (cf. Appendix C).

At this stage, it is worth commenting on the use of the Polish word *karylion* (carillon), which is a direct translation of the French (or English) term *carillon*. As proof of the correctness of its form, numerous examples of similar direct Polish translations can be cited: *bataillon* – batalion (battalion), *bouillon* – bulion (bouillon), *cotillon* – kotylion (cotillion), *médaillon* – medalion (medallion), *postillon* – pocztylion (postilion), *quatrillion* – kwadrylion (quadrillion), *trillion* – trylion (trillion), etc.

It is also hoped that the number of carillons active in Poland will exceed the two instruments described herein, and the third, new one, mobile, recently purchased by Gdańsk Historical Museum [106], and will become, at least approximately, comparable to the number of carillons in other countries such as Denmark (22 instruments), Germany (40), France (55), but not even daring to be compared with Belgium (86) and the Netherlands (167), according to the figures collected by the World Carillon Federation [100]. And then, the more frequent use of the name *carillon* will permit familiarization of it and its universal acceptance.

Turning back to the gist of the topic, attention should be drawn to the existence of territorial boundaries in Europe in the traditional use of church bells. That boundary is related to the method of triggering the sound of a bell: with a hammer – in the case of fixed bells, or with a clapper – in the case of swinging bells. It coincides roughly with the former eastern Polish border as it arises from the tradition of the Orthodox Church in the east, in contrast to the Catholic and Protestant churches in the west. The consequences of the existence of such a boundary are important for the research in the field of sound engineering of swinging bells, which are much richer spectrally and tonally than fixed bells. That distinction is known and described in international campanological literature (Price, 1983; [99]; [103]). Analysis of those differences and their impact on the perceived timbre of sound has been given a lot of attention at Multimedia

Systems Department GUT (Sankiewicz *et al.*, 1994; 1996a; 1996b; 2007). The experience of those works is used, among others, by a group of authors conducting research in the region of Toruń and Chełmno, which is abundant in bells. A new analytical study of the directional properties of sound radiation by the bell has been recently initiated by authors from Cracow (Gołaś *et al.*, 2009). It would be desirable to extend the analysis to the sound of a swinging bell and to take into account the sounds reflected by the walls of the belfry. Combining such a study with examination of range characteristics of the audibility of a bell in the surroundings of the bell tower would also be useful in practice.

Part of the work of the Multimedia Systems Department GUT has been devoted to an entirely new concept of a mechanical system for triggering the sound of a swinging bell with a clapper that rotates around its mounting axis outside the cup of the bell. The concept was presented at a global AES Convention forum (Budzyński *et al.*, 1997).

Another group of publications listed in the Bibliography are extensive works of Russian and Ukrainian authors (Aldoshina *et al.*, 2000; Ivanov–Rostovcev *et al.*, 1991; Nikanorov, 1999; Niunin, 1998). They contain information about campanological stock of instruments, which is of interest precisely because of the aforementioned difference in sound triggering in the regions of Western and Eastern Europe, as well as the prospect of establishing cooperation with researchers of the mentioned countries.

4. Potential future developments in Sacral Sound Engineering

The knowledge and skills in sound engineering gained in the course of research conducted by the authors at MSD GUT proved to be useful when they participated in a major overhaul, supervised by Father Prof. Jan Chwałek, of the great organ in the Leżajsk Basilica (Chwałek, 1997) conducted in 1997. Participation of all the authors, listed in the Bibliography, in other national projects, both organological and campanological, gives hope for their further creative participation in the development of sacral sound engineering. In this regard, the stimulatory effects of the various research centres that are responsible for the education of young students of science or art are of particular importance.

That impact, and therefore the scientific potential of a given scientific centre, may be somehow measured by the dissertations in the field. Complying the publications marked in the References, there have been twelve doctoral dissertations and a habilitation. They testify to the advanced level of scientific expertise of the authors. Another interesting measure to evaluate the developmental potential of the individual centres is the distinction by site of creation of those dissertations; the various centres account for the following: Catholic University of Lublin – 1 habilitation and 4 D.Sc., Gdańsk University of Technology – 5 D.Sc., Warsaw – 2 D.Sc., Cracow – 1 D.Sc. That mini-statistics confirms the leading role

that is attributable to the Catholic University of Lublin in the development of organology studies, and more specifically, to the Chair for Musical Instrument Studies headed by Father Jan Chwałek, Full Professor, Ph.D. It also indicates the considerable research potential in campanology at ZID and at the Sound and Vision Engineering Department, now the Multimedia Systems Department GUT, headed by Andrzej Czyżewski, Full Professor, Ph.D., D.Sc., Eng.

Finally, the importance of periodic publications run by individual centres, facilitating the exchange of scientific information between researchers and helping them to publish results, should be emphasized. Series such as "The Organ and Organ Music" edited by the Academy of Music in Gdańsk, "Open Seminars in Acoustics – OSA" edited by the successive Branches of the Polish Acoustical Society, "Symposia of Sound Engineering and Design" edited by the successive Branches of the Polish Section of the Audio Engineering Society, "The Warmia Studies" edited by the Warmia Diocesan Publications, and, finally, "Studia Organologica" edited by KUL (Catholic University of Lublin) and initiated by the Chair for Musical Instrument Studies, are tools for building scientific and research potential and enhancing the development of Sacral Sound Engineering.

The word "sacral" used in the title also links this article to philosophical problems such as those presented by Father Jacek Bramorski in his book (Bramorski, 2003), historical and liturgical issues (Norman, 1990), and the problems of liturgical music (Tyrała, 2007). Although they seemingly have no effect on the solving of engineering problems of sacral acoustics, there are symbolic cause-and-effect relationships between, for example, the way of arranging the space in a church interior and the concepts about how the cosmos is organized. In addition to the symbolism, those relationships have a practical impact in the form of liturgical changes introduced in 1965 by the Second Vatican Council, for example in terms of the spatial arrangement of elements that should surround the altar in every Catholic church. Therefore, a sound engineer working in a church should be aware of those relationships, both now and in the course of future developments of sacral sound engineering.

At the end of this review, the author would like to share some fresh information found on the Internet, originating from the USA [102], concerning the famous Vilnius organ, built in the Holy Spirit Church by organ builder of D.A. Casparini in 1776. Based on that instrument, which luckily survived the ravages of war, the Eastman School of Music in Rochester, NY has built a replica designed to provide students of organ music with a faithful copy of a prime Baroque instrument. The inaugural concert of Bach music played on the reproduced instrument took place in October 2008 [102]. One must add here that the acoustic properties of the Holy Spirit Church have been the subject of extensive research recently conducted by the well-known Lithuanian acoustician, co-working with the Multimedia Systems Department GUT, Prof. Vytautas Stauskis, Ph.D., D.Sc., Eng, who drew attention, among other things, to the inevitable unevenness and di-

rectional diversity of the sound field in the interior of that church (Stauskis, 2002).

5. Conclusions

In relation to the examples of publishing series mentioned in the previous chapter, a review of which provided a major share of the Bibliography of this article, an essential conclusion becomes apparent. Sound Engineering in general, and Sacral Sound Engineering even more so, are highly interdisciplinary in nature, therefore an intensive exchange of professional information between researchers working on the different issues in various fields is essential for its development. Particularly important is the cooperation and mutual understanding between acousticians and architects, and art historians and musicians. The sacral nature of the object of studies also points to the indispensable cooperation of the clergy. The content of this article, especially Sec. 4, shows how fruitful such cooperation may be.

Further conclusions concern matters that are less general, but still essential. The theme of bells, rarely investigated in this country before, entered (after several years of preliminary studies conducted by ZID) into the field of organ studies at The Organ and Organ Music sessions in 1994, and has since then been kindly treated and included on equal terms in musical instrument studies. The rationale for such treatment is the multitude of engineering problems, common to both instruments, especially in the case of the organ and carillon.

The review of publications and the findings of the author's own research show how many problems in the field of Sacral Sound Engineering remain to be tested and resolved. Indication of some of those problems was one of the secondary objectives of this work.

In the summary of this review article, one cannot avoid mentioning the shortcomings of Polish literature in the subjects discussed here. Although one should be glad that there are relatively recently updated inventories of organs in Poland, they are not complete. They are lacking, in particular, complete and easily accessible data on the national organ stock, and especially on bells. The existing collections of data at ODZ still have not been made available on the Internet (except for summaries). The few available publications of the advocated type show severe gaps. There are no publications presenting more comprehensive source materials on both historic and contemporary buildings, including relevant illustrative material. They should be mostly web publications, easily accessible to a wide range of people interested in the subject.

Therefore, a new initiative to stimulate the actions of authors willing to undertake further research and publish their work properly presenting the Polish share in European and global achievements in campanology and organology is highly desirable. In order for such an initiative to be effective, it should be initiated by the Ministry of Culture and National Heritage, in cooperation with the Polish Episcopate, and be addressed directly to potential authors and researchers.

Appendix A.

<table>
<tr><td colspan="2">1. Locality
GDAŃSK-WRZESZCZ</td><td>2. Community
GDAŃSK</td><td colspan="2">3. Voivodship
pomorskie</td><td>19. Contents of original folder
ten supplementary photographs</td></tr>
<tr><td colspan="2">4. Location
Wrzeszcz, ul. Sobótki 20
St St Peter's & Paul's Church</td><td>5. Owner's address
Garrison Church,
ul. Sobótki 20</td><td colspan="2">6. Diocese
Gdańsk / military pastorate
Roman Catholic Parish</td><td></td></tr>
<tr><td colspan="2" rowspan="4">  </td><td>12. Dimensions

400 × 500 × 350
height width depth</td><td colspan="3" rowspan="4">18. Description, marks, signatures, inscriptions
Organ-case (Prospect) neo-gothic, one-sectional.
Massive frame, divided into pilasters, with centrally situated door to the instrument interior, serves like a base of the organ-case conception. Each of the four stylized doors is decorated with profiled cornices shaped like gothic window recesses. The frame is separated from the proper organ-case by means of thick cornice and a line of a pseudo-phytogenic ornament.
Principal pipes of the prospect are disposed in one plane, fastened together with wooden braces into a central tower and into two pairs of ogival arches at the ends. The central tower is crowned by a gabled hood moulding and a modest cinquefoil, decorated with frogs, without a distinct crown. The pairs of side turrets, finished with triangular pinnacles, are ornamented with frogs and liliaceously profiled ogival arches. Each is crowned with a lily. Pinnacles are diversified by transverse and perpendicular beams, protruding from underneath pilasters, separating relevant turret planes, ornamented with frogs.
Within 2/3 of frame height the edging transverse beams divide perpendicular pilasters from pinnacles.
The whole body, like a "little castle" looks neatly and harmoniously.
This organ provides one of a few preserved testimonies of a return to the baroque concept of organ sound, which was being realized before the Second Wold War by the Kemper's organ-building firm (instruments in St. Mary Basilica in Gdańsk were destroyed, those in Frombork cathedral rebuilt). Interesting are solutions applied in wind-chests. The element of the action within the I Manual is a wedge shaped pouch valve inside the air channel of the chest, furnishing wind through a conduit directly to the pipe. In the remaining divisions those valves reinforce the action of electromagnets, being attached outside the chest channel, where trackers pulling pipe valves for particular tone are installed. Remarkable are the facts: supplementary wind-chests for three upper pedal tones and cone-chest for Rauschpfeife, as well lack of room on wind-chests for some stops signed in the console. They seem to confirm an oral information about other organs existing here in the past (vide Handbuch...). This organ is fully worthy of being investigated in detail.</td></tr>
<tr><td>13. Material
Technique

varnished timber
gildings</td></tr>
<tr><td>14. Date
Style

beginning of XX century
neo-gothic</td></tr>
<tr><td>15. Builder, School

Organbuilders' workshop
E. Kemper und Sohn</td></tr>
<tr><td colspan="2">16. Condition
(condition)
Restorations

prospect – very good
instrument – good</td></tr>
<tr><td>8. Photograph taken by

Gustaw Budzyński</td><td>10. Negative
preserved by

the author</td><td colspan="3" rowspan="2">17. Sources and literature (in State Archives in Gdansk):
Königliches Konsist. der Westpreussen, 977, 1112.,
Akta Senatu W. M. Gdańska, Bau der Luterkirche in Danzig Langfuhr, zesp. 230, poszyt 3314, Handbuch fur die Evangelischen in Danzig,
Danzig 1919, s. 81–83 / Organs are ascribed to the firm M. Terletzki/.</td><td>20. Remarks Saved in Excel program; translated from original chart, and modified
by G. Budzyński</td></tr>
<tr><td>9. Photograph date
1996.</td><td>11. Negative No.
3</td><td>21. Material collected by, date:
The folder set up by:
P. E. Lewko 7.09.1993.</td></tr>
</table>

22. Action
I – electropneumatic
II, III, P – electropneumatic/mechanic

23. Wind-chests
I – register, pocket chest
II, III, P – register, side-valve chest

24. Console

free-placed

Keyboard	Number of keys	from	to
I	54	C	f”’
II	54	C	f”’
III	54	C	f”’
Pedal	32	C	f”

25. Bellows

floating multifolded

a) Number	b) Dimensions
1 collecting 2 equalizing	116 / 91 cm

26. Bellows drive
electric blower AUG. Laukhuff Nr 124251
motor Nr 111405

27. Organ-builder
E. Kemper und Sohn – LÜBECK

28. Erection year
1939–1940 / ? /

30. Specification

29. Number of stops /39/, 34 playing

UNTERWERK		HAUPTWERK		KRONWERK		PEDAL		KOP.
Gedackt	16	Bordun	16	Gedackt	8	Prinzipalbas	16	I/II
Ital.Prinzip.	8	Prinzipal	8	Quintade	8	Subbass	16	III/II
Salicet	8	Holzflöte	8	Prinzipal	4	Gedact	8	III/I
Quintade	4	Gemshorn	8	Rohrflöte	4	Octave	8	I/P
Blockflöte	4	Octave	4	Waldflöte	2	Quintade	4	II/P
Gemshorn	2	Gedackt	4	Zimbel	2f	Nachthorn/-/	2	III/P
Quinte	1 1/3	Quinte	2 2/3	Sedez /+/	1	Rauschpfeife	2f	
Terz	1 3/5	Octave	2	Krummhorn /!/	8	Posaune	16	
Septime	1 1/7	Mixtur	4f	Singend Regal /-/	4	Dulcian /-/	16	
Oboe	8	Trompete /-/	8	tremolo				
tremolo		Trompete	4					

POM.: 3 free combinations, P, F, T, switch for reed-pipes, voltmeter, pressure meter, crescendo shaft swell-box pedal switch/open – closed/.

EXPLANATIONS: /-/ lacking stop and its room on wind-chest, /-/ lacking stop, /+/ stop inserted by D. Wierucki, produced by J. Mollin, /!/ stop recovered by D. Wierucki, remnants built-in.

31. Alterations: date, firm, extent
Inscription on the collecting bellow: “Organ overhauling 1.X.1960.
It is forbidden to put anything on bellow bag nor to take away the bricks.” – J. Plenikowski from Kartuzy.
1985–87, D. Wierucki, insertion of stop Sedez.
1992, W. Wawryków.

Appendix B.

<table>
<tr><td colspan="3">1. Definition
Music instrument – Bell</td><td colspan="2">2. Material, technique
bronze, casting</td><td rowspan="2">11.
Gdańsk
.....
(locality)

Gdańsk
.....
(community)

gdańskie
.....
(voivodship)</td></tr>
<tr><td>3. Style
neo-gothic</td><td>4. Date
1926</td><td>5. Author
Bachert brothers
Karlsruhe</td><td>6. Dimensions:
Diameter 113 cm
Height 97 cm
Crown height 20 cm</td><td>7. Quantity
1</td></tr>
<tr><td colspan="5">8. History
The bell founded for the church in the year 1926.</td><td>12. Location
Church tower (see photograph)
St St Peter’s & Paul’s Church
Gdańsk-Wrzeszcz, ul. Sobótki 20</td></tr>
<tr><td colspan="2" rowspan="3"></td><td colspan="2" rowspan="3">9. Description, marks, signatures, inscriptions

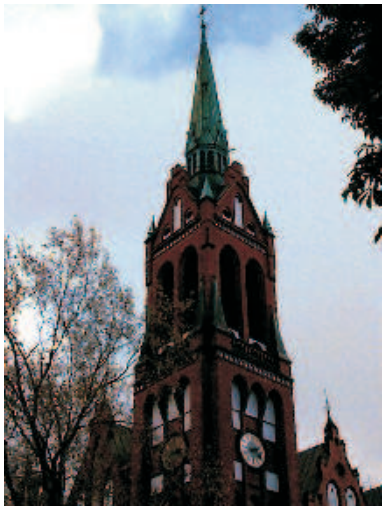
Inscriptions on the upper part of the bell waist:
Lasset die Kindlein zu mir kommen * Marc. 10, 14. *
O heiliger Geist, kehr bei uns ein!
– on the lower part of the bell waist:
Gegossen i. J. 1926 von Gebrüder Bachert, Karlsruhe i. B.
In the middle of the bell waist there is a sign shaped as a dove holding a twig in his beak.
The shoulder of the bell is encircled with two belts of profiled overflown castings, with a florid rippled friese between, interspersed with a motif of stylized palm.</td><td>13. Owner’s address

Roman Catholic Parish
Gdańsk-Wrzeszcz</td></tr>
<tr><td>14. Accessibility

after consent of the Rector</td></tr>
<tr><td>15. Designation, date, No</td></tr>
<tr><td colspan="2"></td><td colspan="2">10. Sources and literature

Tomasz Korzeniowski, the documentary folder set up 10.08.1993.</td><td>16. Records</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td>17. Iconography and negatives, No.

Photographs enclosed in item 20 (Remarks) are saved digitally; they are accessible at the founder of the chart (see item 21).</td></tr>
</table>

18. State of preservation and conservation needs very good – employed to everyday ringing for church services an overhaul of electromechanic facility for bell swinging is recommended		a. Date and recorder's name Gustaw Budzyński December, 1997
19. Conservation	a. Duration	b. Conservator
20. Remarks  		21. Filled by Gustaw Budzyński 15.12.1997 22. Checked by Date

Appendix C. Sacral buildings investigated by the Sound/Sound and Vision/ Engineering Department of TUG in the years 1977–2002

St. Stanislaus and St. Wenceslas' Cathedral on Wawel Hill (bells only), 1996;
Holy Trinity Cathedral in Gdańsk-Oliwa, 1977, 1979;
Immaculate Conception of the Blessed Virgin Mary Cathedral in Koszalin, 1982;
St. John the Baptist and John the Evangelist's Cathedral in Toruń (bell only), 1996, 2002;
Assumption of the Blessed Virgin Mary Cathedral in Frombork, 1995;
Assumption of the Blessed Virgin Mary Cathedral in Pelplin, 1980;
Assumption of the Blessed Virgin Mary Cathedral in Włocławek, 1980
Blessed Virgin Mary Co-Cathedral in Gdańsk, 1979, 1981;
St. John the Baptist's Co-Cathedral in Kamień Pomorski, 1982, 1996;
St. Nicholas' Basilica in Gdańsk, 1979, 1982;
Assumption of the Blessed Virgin Mary Basilica at Jasna Góra (carillon only), 1992;
Annunciation of the Blessed Virgin Mary Basilica in Leżajsk, 1997;
Collegiate Church of the Blessed Virgin Mary the Queen of Poland in Gdynia, 1983;
St. Peter and Paul's garrison Church in Gdańsk-Wrzeszcz, 1996-1997;
Church and Sanctuary of the Motherhood of the Blessed Virgin Mary in Trzebiatów, 1996;
Sacred Heart of Jesus Christ Church in Gdańsk-Wrzeszcz, 1995;
Visitation of the Blessed Virgin Mary Church in Bardo Śląskie, 1983;
Visitation of the Blessed Virgin Mary Church in Święta Lipka, 1981;
Exaltation of the Holy Cross Church in Pruszcz Gdański, 1979;
Transfiguration of Jesus Church in Przerośl, 1998;
St. Barbara's Church in Gdańsk, 1986;
St. Bartholomew's Church in Gdańsk, 1986;
St. Bridget's Church in Gdańsk, 1979, 1997;
St. Elizabeth's Church in Gdańsk, 1979;
St. George's Church in Sopot, 1983;
St. James' Church in Gdańsk, 1986;
St. Joseph's Church in Gdańsk, 1979;
St. Joseph's Church in Krzeszów, 1982;
St. Catherine's Church in Gdańsk, 1979, 1995;
St. Catherine's Church in Warszawa-Służew, 1998;
St. Casimir's Church in Radom (bells only), 1997;
St. Nicholas' Church in Łomna (bell only), 1998;
St. Peter and Paul's Church in Chmielno, 1980;
St. Stanislaus and St. Wenceslas' Church in Świdnica, 1982;
St. Teresa of Avila Church in Wiżajny, 1998;
Holy Trinity Church in Gdańsk, 1979;

St. Adalbert's Church in Kielno, 1987;
Assumption of the Star of the Sea Church in Sopot, 1983;
Finding of the Holy Cross Church in Warsaw (bell only), 1998;
Corpus Christi Chapel in Gdańsk-Morena, 1995;
St. Anne's Chapel in Gdańsk, 1979;
Sanctuary of Our Lady of Sorrows, Queen of Poland, in Stary Licheń (bell only), 1998;
Holy Trinity Orthodox Cathedral in Hajnówka (bells only), 1988;
Hall and the organ at CATHOLIC UNIVERSITY OF LUBLIN in Lublin, 1983, 1984.

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